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TECHNOLOGY HANDBOOK

Technology Utilization Division

WELDING FOR ELECTRONIC ASSEMBLIES

From George C. Marshall
Space Flight Center
Huntsville, Alabama

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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NOTICE

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FOREWORD

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This is the second in a series of volumes on Reliable Electrical Connections. This volume covers the theory requirements and fundamental techniques of interconnecting electronic components by resistance spot-welding. A thorough understanding of the theory of resistance spot-welding along with good workmanship and process control are the factors necessary to attain the required reliability.

THE DIRECTOR, *Technology Utilization Division*
National Aeronatics and Space Administration

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Chapter 1

INTRODUCTION

The trend toward package miniaturization has resulted in many new packaging concepts. One of the concepts presently in use is the welded package. The guidance systems of the Polaris, the test data system of the Dyna-Soar, portions of the Titan electronics, and portions of the Pershing Ground Support Equipment have used the welded package technique. The Saturn project has a number of welded packages either in use or in planning; for example, the guidance computer.

The welded package offers a greater reliability of operation than do other available packaging methods. Although welding is an old process, its use as an interconnection medium for electronic components is relatively new. Its first application to the electronic field was in the manufacture of vacuum tubes. In 1954, a research scientist at Hughes Aircraft Company proposed that the welded technique be adapted for the interconnection of electronic components. This technique has been developed to the point of application in the production of miniature electronic packages.

Welding is not a panacea for the interconnection problems and will never entirely replace soldering. Each method has its advantages and disadvantages; thus, careful consideration should be given to the method of interconnection to be used for any specific application.

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Chapter 2

FUNDAMENTALS

Welding is defined as the joining of two materials by the formation of a homogeneous alloy at the interface of the materials. Many welding processes are in use, as shown by figure 1. The process to be discussed here is the resistance spot-welding process. Other welding processes have been, or are now being, investigated as a means for interconnecting electronic components. Some of these processes are arc welding, ultrasonic welding, and percussion welding. However, these are still in the research and development stage.

Resistance spot-welding is a thermal process wherein the inherent resistance of the materials to the flow of electric current is employed to generate the required heat for welding. Basically, the materials to be welded are placed between two electrodes which exert pressure on the materials. A high intensity current is then passed through the electrodes and the materials to be welded for a precise length of time. The current flowing through the resistance of the materials generates heat which produces the weld.

JOINING MECHANISM

The joining mechanism of welding may be classified as being either a fusion or a forging action. The fundamental difference between the two mechanisms is the temperature at which the joining weld occurs. The heat generated is a function of the thermal and electrical characteristics of the materials to be welded. These characteristics govern which joining mechanism takes place. Figure 2 illustrates the two basic welds.

Fusion occurs when the temperature is great enough to cause melting of the weld materials at the point of interface. The molten materials are confined within the weld materials and, upon cooling, solidify to a cast structure, termed a "nugget," which binds the materials together. Lighter metals and materials such as iron, steel, and nickel exhibit this type of weld.

The forge weld is basically a solid state one. The temperature reached is not high enough to cause melting but high enough to cause the materials to reach a plastic state. The pressure exerted by the electrodes forces the materials into intimate contact, and the proximity of the atoms of the two materials at the interface causes a solid state bond. There is no evidence of a nugget in the forge process. Copper and other metals possessing low resistivity and high thermal conductivity are joined by this type of weld since it is difficult to localize the heat at the interface.

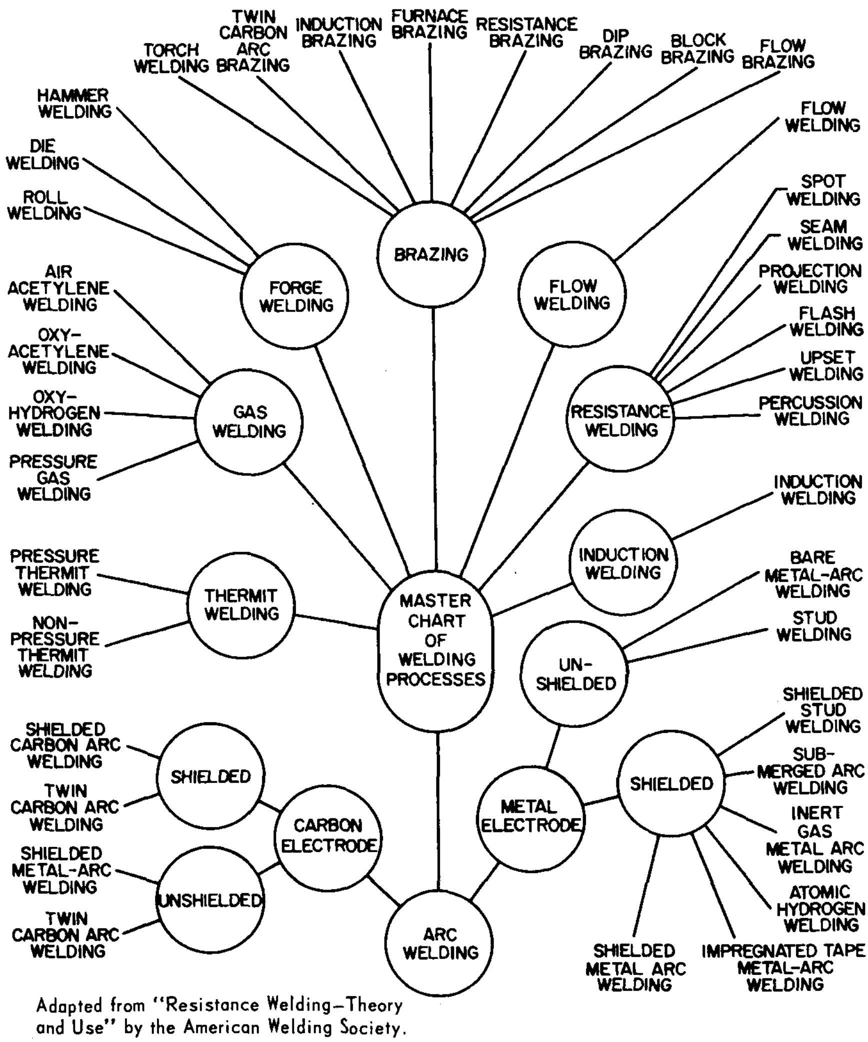
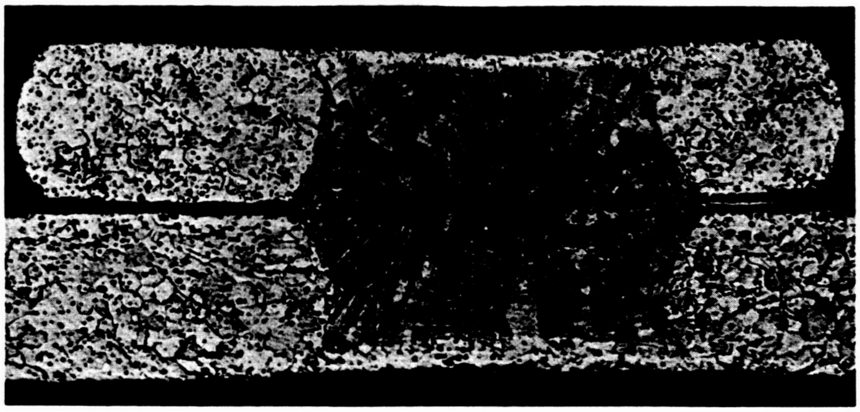
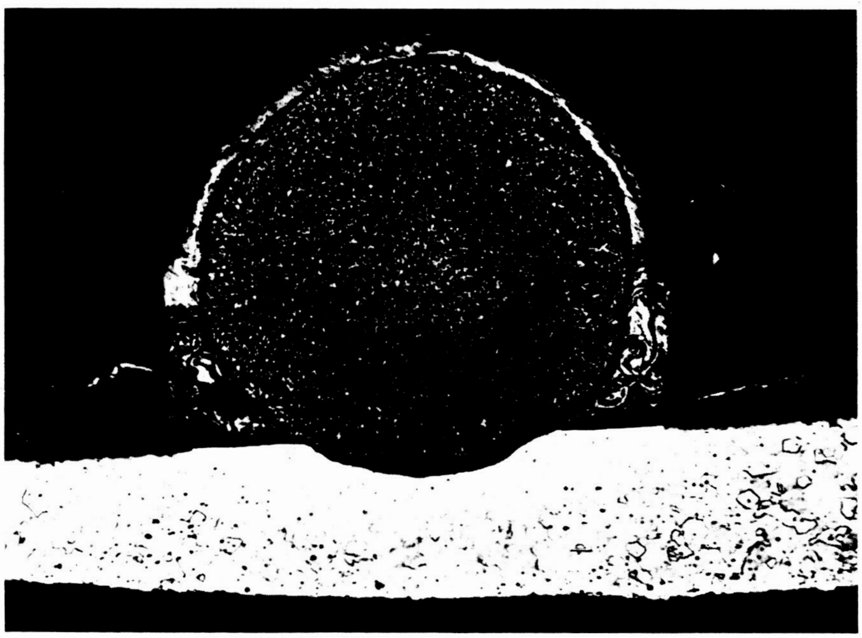


FIGURE 1.—Master chart of welding processes.



a. Fusion-type weld exhibiting nugget (nickel to nickel, 0.010 in. x 0.047 in. ribbon).



b. Forge-type weld (0.010 in. x 0.047 in. nickel to 0.025 in diameter dumet).

FIGURE 2.—Basic types of welds.

Of the two basic welds, the fusion weld exhibits greater strength and is more desirable. However, the nature of the materials encountered in welding electronic components is such that most welds have been of the forge type.

HEAT GENERATION

From the previous paragraphs, it is obvious that heat must be generated to produce a weld. The heat is produced by a high intensity current flowing through the resistance of the materials to be welded.

Current flowing in a resistive circuit generates heat which may be expressed by equation (1).

Equation (1) $$P=I^2R$$

P = Power (watts)
I = Current (amps)
R = Resistance (ohms)

This equation gives an instantaneous value and does not take into consideration the element of time. Taking time into consideration, the equation becomes:

Equation (2) $$W=0.24I^2RT$$

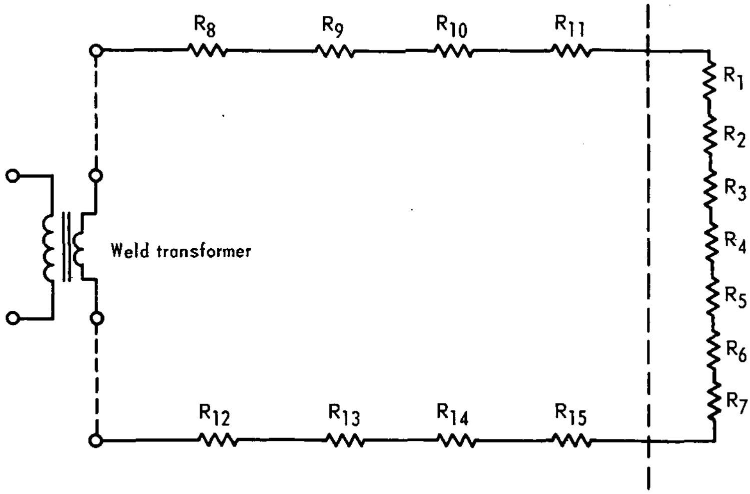
W = Energy (calories)
I = Current (amps)
R = Resistance (ohms)
T = Time (seconds)
0.24 = Conversion Factor

Equation (2) computes the amount of energy generated by a given quantity of current flowing through any specified value of resistance for a precise length of time.

RESISTANCE OF THE WELD CIRCUIT

The resistance of the weld circuit appears as shown in figure 3. The current will be the same at any given point in a series circuit, and the heat generated at this point will be directly proportional to the resistance at this point. Heat generated anywhere but at the place of the weld is wasted energy. Therefore, all resistances of the weld circuit, other than at the point of the weld, should be minimized. Of the resistances shown in figure 3, all but seven can be eliminated in the analysis of the weld circuit.

A number of factors will influence the resistance of the contact areas. The resistance of zones 2, 4, and 6 varies with electrode pressure, cleanliness, resistivity, geometry of the electrodes, and the materials.



R_1 and R_7	-	resistance of electrode
R_2 and R_6	-	contact resistance between electrode and work material
R_3 and R_5	-	resistance of work materials
R_4	-	contact resistance at interface of work materials
R_8 and R_{12}	-	contact resistance between cables and power supply
R_9 and R_{13}	-	resistance of cables
R_{10} and R_{14}	-	contact resistance between cables and weld head
R_{11} and R_{15}	-	contact resistance between electrode clamp and electrode

NOTES

1. Resistances R_8 through R_{15} are equipment design factors. In a well-designed machine, these resistances will be minimized.
2. Resistances R_1 through R_7 will depend on the electrode and work materials. These resistances affect the heat generation at the weld point.

FIGURE 3.—Resistances of the weld circuit.

TIME

The equation for heat generation shows that the heat produced is proportional to the time duration of current flow. Thus, time duration must be precisely controlled to produce consistent welds. In the case of stored energy equipment, this time is fixed and may be considered a constant. The pulse width of most stored energy machines is in the range of 1 to 3 milliseconds, although equipment is available with longer pulse durations.

CURRENT

The current flowing in the weld circuit plays the largest role in the generation of heat, since the heat produced is proportional to the square of the current. However, the amount of current flowing in the weld circuit is a functional result of the weld circuit resistance and applied voltage.

HEAT BALANCE

When the maximum amount of heat is produced at the interface of the two materials to be welded, namely zone 4 in figure 4, the fusion zones in the pieces of material to be joined undergo approximately the same degree of heating. This is the desired condition and is termed heat balance.

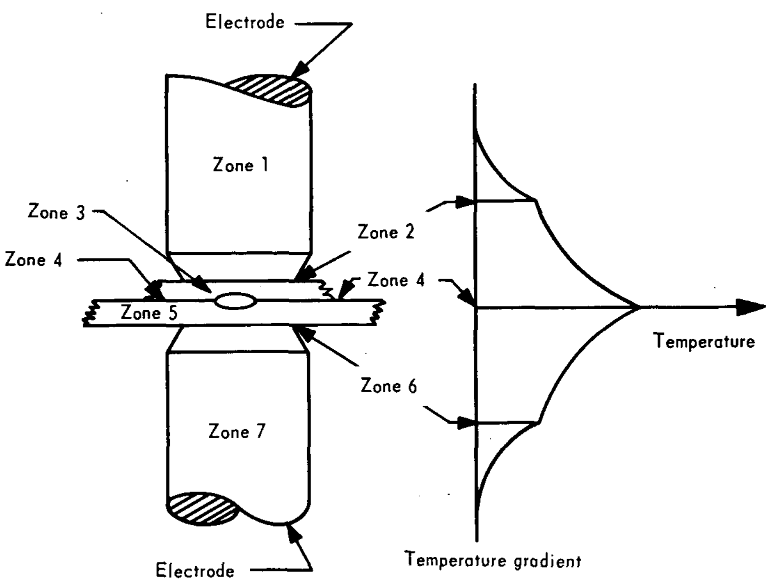


FIGURE 4.—Resistance zones and temperature gradients of resistance spot-welding.

When different types of materials, or materials of different thicknesses, are to be joined, zones 3 and 5 present different values of resistance to the weld current and therefore shift the temperature gradient curve so that heat balance no longer occurs. The resistance of the materials to be welded is the biggest factor in heat balance, although the resistance of the electrodes must also be considered.

Heat balance is affected by all of the following:

a. Relative thermal and electrical conductivities of materials to be joined.
b. Relative geometry of parts at joint.
c. Thermal and electrical conductivities of the electrodes.

d. Geometry of electrodes.

By judicious choice of electrode material and proper electrode geometric design, the problem of improper heat balance can be solved. The methods employed to create proper heat balance are discussed in the section dealing with electrodes.

The seven zones of weld circuit resistance and their related heat gradients are shown in figure 4. Zones 1 and 7 represent the resistance of the electrode materials. The temperature at these zones is fairly low because of the relatively low resistance and large radiative surface of the electrode. The areas labeled 2 and 6 represent the contact resistance between the electrodes and the weld materials. The temperature at these points is fairly high and approximates fusion temperature. However, because of the conductivity of the electrodes, part of the heat is conducted away from these zones, and fusion temperatures are not reached. Zones 3 and 5 are resistance zones due to the internal resistances of the weld materials. The temperature gradient is increasing here and is close to the fusion temperature. The zone labeled 4 presents the largest resistance and, consequently, reaches the highest temperature. This zone is the contact resistance at the interface of the weld materials. The heat generated at this point is isolated from the electrodes by the hot spots of zones 2 and 6.

PRESSURE

Equation (2) takes into account the electrical variables of the weld circuit. However, it does not reflect the pressure requirement which is essential to provide forging. The pressure exerted by the electrodes on the work materials serves three main functions:

a. Contains the molten nugget during current flow when high internal pressures are built up as a result of the heat of welding.
b. Maintains intimate contact between the materials to be welded and also between the materials and electrodes.
c. Provides forging action during nugget solidification so that thermal shrinkage will not promote cracking or porosity.

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Chapter 3

DETERMINATION OF OPTIMUM PARAMETERS

Since pressure, time, and energy are the controllable variables for producing a weld, proper application of these variables is of paramount importance for producing the optimum weld.

The operator must prepare an iso-strength diagram to determine which parameter of each variable will result in the strongest, most *consistent* weld. The iso-strength diagram is a graphical representation expressing the strength of the weld as a function of energy and pressure. When the diagram is completed, it will show the operator which parameters are most suitable for producing optimum welds with specific materials.

On the iso-strength diagram, pressure is plotted on the ordinate end energy on the abscissa. At each set of coordinates within the plot, the strength of the weld produced at these coordinates is recorded. The plot may be completed by selecting increments of energy and pressure and then producing welds at each coordinate point. However, this is a lengthy procedure, and a statistical approach has been developed which produces the same results in a much shorter period.

The statistical approach involves selecting an arbitrary set of starting points. Several welds are made at this point and pull-tested. The average breaking strength of this group of welds is then recorded at the coordinate point on the iso-strength diagram. Four additional points are selected at definite increments of pressure and energy in such a manner that the four points fall around the initial point. A number of welds are made at each of these points, pull-tested, and the average break-strength recorded at the respective coordinate points. The point which displays the highest break-strength is the direction in which future tests proceed. Select another arbitrary point that is in the direction indicated by the preceding test. Use the aformentioned procedure to determine the direction in which to continue testing. This procedure continues until the point is reached where "spitting" occurs. The diagram is then analyzed and the region which exhibits the strongest constant strength before spitting occurs is outlined. The center coordinates of this region become the machine settings for production welds.

For example, find the best machine settings for welding two 0.010-inch by 0.047-inch nickel ribbons together. The solution to this problem may be found in the following manner.

1. Record the materials, electrode types, date, and such in the appropriate places on the iso-strength diagram. (See fig. 5.)
2. Select any arbitrary point as a starting position. In this case, the initial point is 3 pounds pressure and 10 watt seconds of energy. Five welds are made at this point, pull-tested, and the average strength calculated. The average strength (25 pounds) is then recorded. (See step 1, fig. 5.)
3. Select four points around the initial point to determine in which direction to proceed. Increments of one pound are selected for pressure, and increments of 2 watt seconds are chosen for energy. The points to investigate then become (8, 4), (12, 4), (8, 2), and (12, 2). At each of these points, five welds are produced, pull-tested, and the break-strength averaged. One additional point is investigated at (12, 5). This completes step 1, and all that remains is to determine which point to use as a starting value for step 2. (See fig. 5.)
4. From the values obtained in step 1, it is evident that increased values of pressure and energy are necessary to produce the strongest weld. The starting value of step 2, then, is selected as (16, 4). Peripheral points are selected as in step 1 and the entire procedure repeated.

In the example under consideration, four steps are necessary before the iso-strength diagram is complete.

The complete iso-strength diagram is shown in figure 6. All that remains to be done is to select the area that produces consistently strong welds. The area selected for this case is shaded, and the center coordinates of the shaded area become the settings used for production work.

The area selected should now be verified for repeatability. This is accomplished by taking a large number of samples and performing a metallurgical examination of some and pull-tests on the rest.

Selection of increments for varying the pressure and energy settings for iso-strength tests may be made in any convenient units. Those selected for the preceding example were 1 pound of pressure and 2 watt seconds of energy. However, more critical materials may dictate that smaller increments be used, such as 0.5 pound of pressure and 1 watt second of energy.

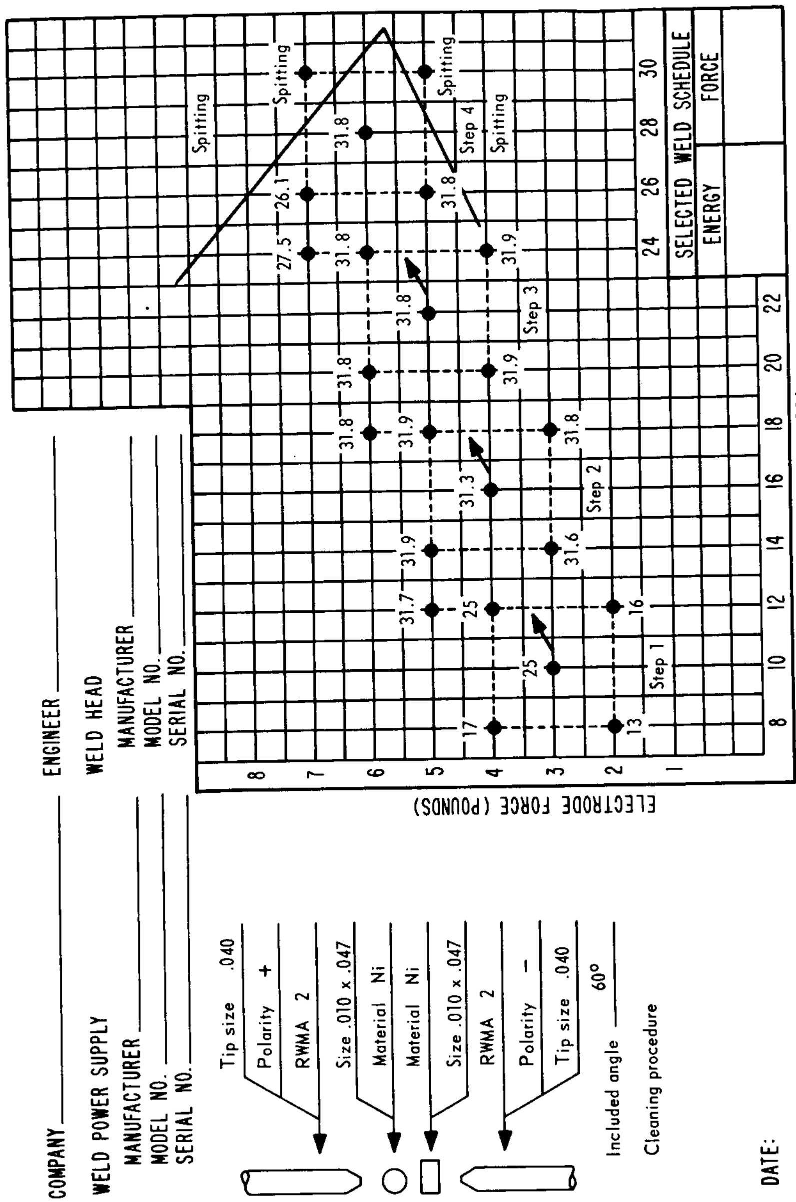


Figure 5.—Preparing the iso-strength diagram.

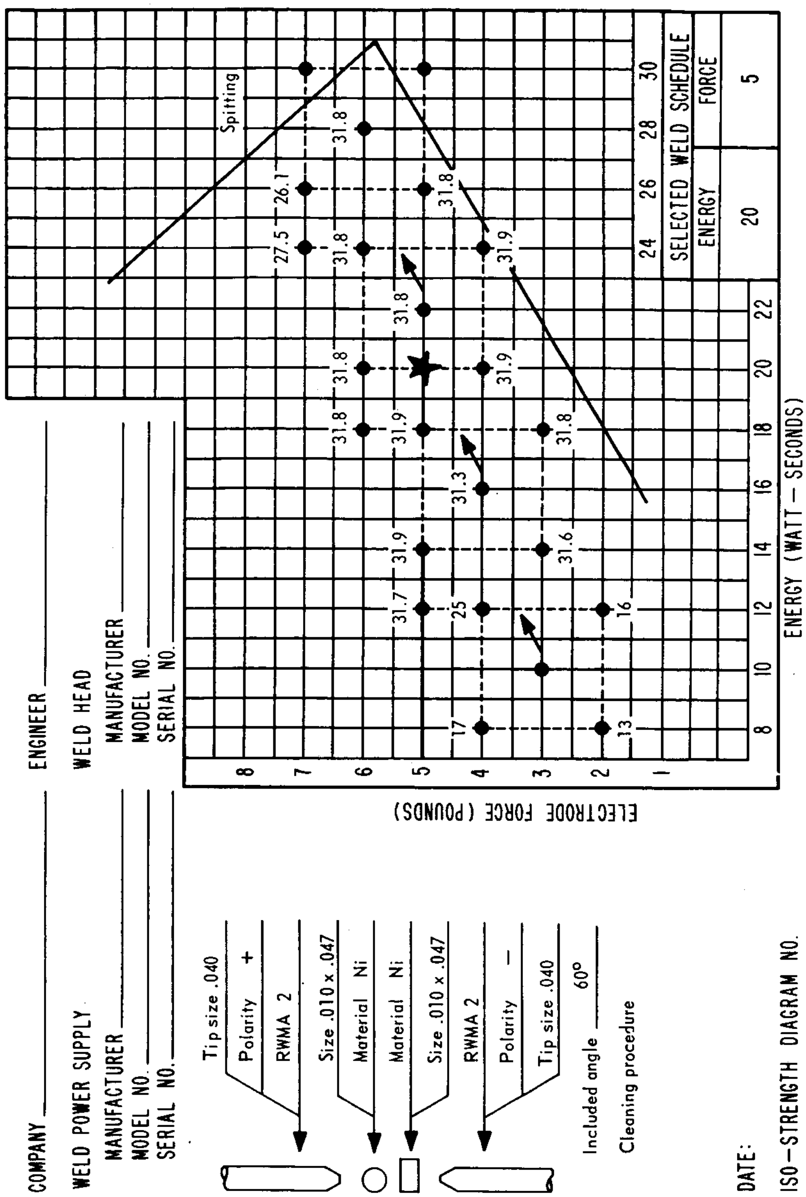


FIGURE 6.—The finished iso-strength diagram.

Chapter 4

EQUIPMENT

The equipment used for resistance spot-welding must meet the following requirements:

a. Ability to supply high current for a short time.

b. Ability to exercise precise control over time and current.

c. Ability to supply a forging pressure with rapid follow-up.

These requirements relate directly to the three main variables of welding over which the equipment can exert control: energy, time, and pressure. This control is accomplished by three main equipment subsystems: the electrical system, the timing and control system, and the mechanical system.

The electrical system provides the energy required for welding and a path to conduct the flow of current to the materials to be welded. This system will consist of the power supply, the interconnecting cables, and the electrodes.

The timing and control system controls the amount of current delivered to the weld zone and the time during which it flows.

The mechanical system provides the pressure for forging. The welding head and the means for supplying the force to actuate the welding head constitute this system. The welding head may be actuated by use of a foot pedal or it may be operated automatically by air or hydraulic power.

POWER SUPPLIES AND CONTROL CIRCUITS

The current required for welding is developed in the power supply. Basically, there are two types of power supplies for developing the current: a.c. power supply and stored-energy power supply.

A.C. POWER SUPPLY

The current which flows in the weld circuit is alternating current (a.c.). This current is taken directly from the line source and fed to the primary of a step-down transformer. The result is a low voltage, with a corresponding high current which is induced into the transformer secondary supplying the weld circuit. This type of equipment is sometimes referred to as direct-energy equipment because it obtains the energy directly from the line source. Normally, the line current is controlled by thyratron tubes.

The thyratrons are connected in an inverse parallel arrangement so that one tube conducts on the postive half cycle and the other tube conducts on the negative half cycle. The thyratron operation is controlled by the timing and control circuit which controls the bias on the thyratron grids; by shifting the phase of this signal, the current magnitude is controlled. Figure 7 illustrates the current-voltage relationship in an a.c. power supply. Since heat is a function of the square of the current, heat can be controlled by varying the current, which is controlled by the thyratron operation. The total heat produced is determined by the number of cycles during which the tubes conduct. Thus, an increase in heat can be obtained by allowing conduction over a greater number of cycles.

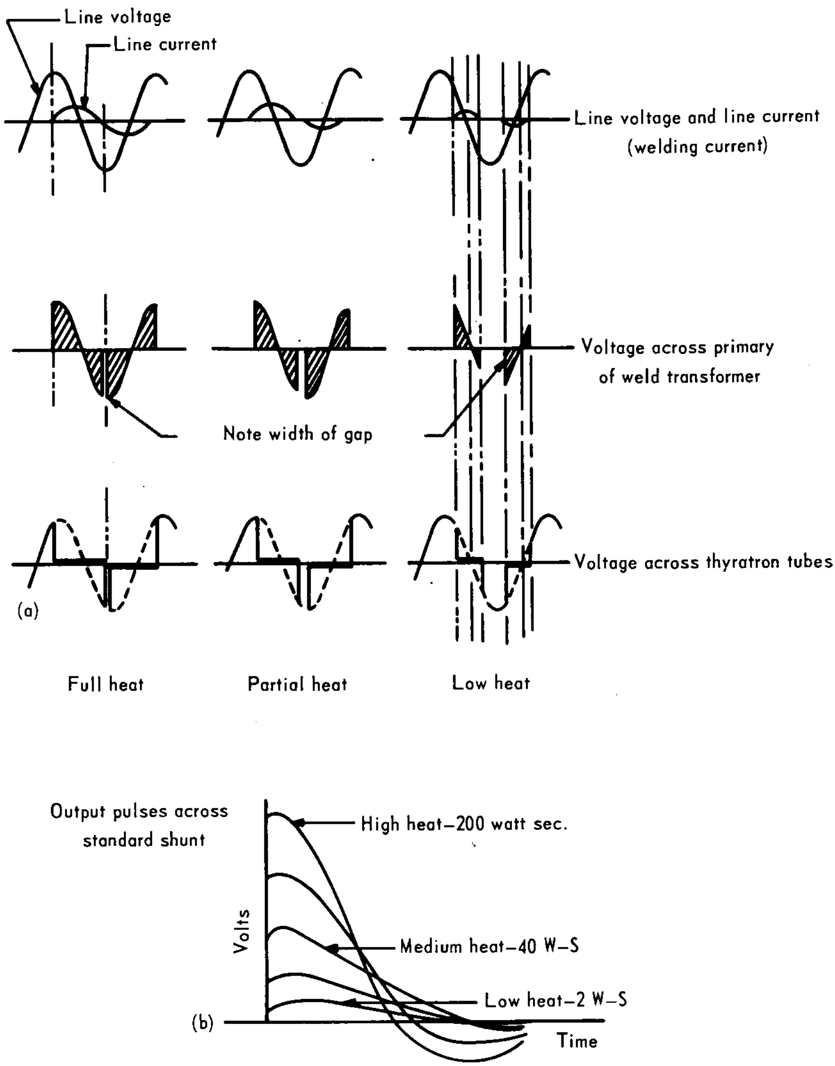
Further refinements can be made to a.c. equipment so that variation of the current's up slope and down slope can be obtained.

This type of equipment will produce reliable welds; however, the construction of weld schedules requires a knowledge of advanced statistical techniques.

STORED-ENERGY POWER SUPPLY

As implied by its name, this power supply stores electrical energy until it is used for welding. The method used for storing the energy may be any one of three different types: electro-magnetic, electro-chemical, or electro-static.

Electric-magnetic power supplies use the energy stored in a magnetic field to provide current for welding. Electro-chemical power supplies utilize the energy stored in storage batteries. Theoretically, these two methods are feasible, but economic factors have prevented their development. The most popular type of equipment for welding electronic components is the electro-static type. The popularity of electro-static welding results from the ease of operation and favorable economic factors. This type power supply stores electrical energy in a capacitor bank which can be discharged when current is needed. Storage of the energy is accomplished when the a.c. line signal is stepped up, rectified, and the resulting high voltage stored in a capacitor bank. The amount of energy stored is varied by varying the capacitor charge-voltage and is expressed by the equation $W=\frac{CV^2}{2}$. The capacitor is discharged through the weld transformer, resulting in a single pulse of current at the weld zone. The higher the voltage stored, the higher the pulse amplitude and the greater the amount of current that is delivered. The pulse duration is constant and is usually in the range of 1 to 3 milliseconds.



a. Heat control in a.c. welding machine.
b. Heat control in stored energy machine.

FIGURE 7.—Heat control in welding machines.

WELDING HEADS

The welding head and its associated actuating mechanism serves the purpose of holding the electrodes and providing necessary forging pressure. Welding heads should meet the following requirements:

a. Must possess low inertia to allow the electrodes to follow the minute expansions and contractions that take place in the work materials during the welding operation.
b. Must be capable of providing repeatable forging pressure.

ELECTRODES

Electrodes are available in many sizes and compositions and have been categorized into groups by the Resistance Welding Manufacturers Associatioin (RWMA). Group A consists of copper based alloys, and Group B consists of copper-tungsten alloys. The groups are further divided into numerical classes. In general, the lower the number, the better the electrical properties, and the higher the number, the better the mechanical characteristics. Table 1 illustrates the types most commonly used in welding electronic components; it does not include all classes of electrodes. A complete chart can be found in most welding handbooks.

TABLE 1.—*Electrode Groups and Classes*

RWMA group	RWMA class	Recommended for
A Copper Base Alloys	1	Aluminum, Magnesium, Nichrome, Platinum.
	2	Alnico, Brass (Yellow), Bronze (Phosphor), Constantan, Beryllium, Gold, Iridium, Iron, Kovar, Molybdenum, Monel, Nickel, Tantalum, Tungsten, Steel.
	3	Brass, Silver, Copper.
B Copper-Tungsten Alloys	13 (Tungsten)	Copper (Used to obtain heat balance) (available as tips or entire electrode).
	Moly	Copper (eliminates sticking and used for heat balance) (available in tips or as entire electrode).

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The ideal characteristics for an electrode to possess are:

a. High thermal conductivity to dissipate heat away from the electrode work material interface.
b. Low specific resistivity to minimize the build-up of heat in the electrodes.
c. High wear and strength to maintain uniformity of electrode geometry.

Usually, it is not possible to obtain electrodes with all these characteristics, and a compromise must be made. In welding electronic components, RWMA #2 will suffice for most applications. For welding high conductivity materials (such as copper), RWMA #13, molybdenum, or tungsten electrodes are used. The entire electrode may be of molybdenum, or tip inserts may be used, the latter being much less expensive.

When welding dissimilar materials, or materials of unequal thickness, the heat unbalance caused by the different conductivities of the weld materials can be offset by the use of electrodes of different materials. Generally, electrodes having a high resistance, such as molybdenum or tungsten, are required for welding materials of high conductivity. Conversely, electrodes having low resistance (RWMA #2) are required for materials having low conductivity. This electrode/material relationship helps to maintain the proper heat balance at the weld interface. Another method for obtaining heat balance is to decrease the face area of the electrode which interfaces on the higher conductivity material. This will increase the current density through the material. (See fig. 8.)

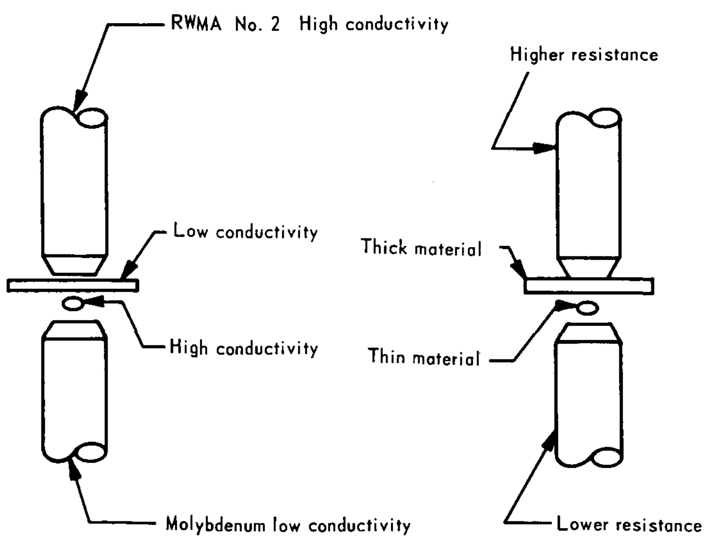
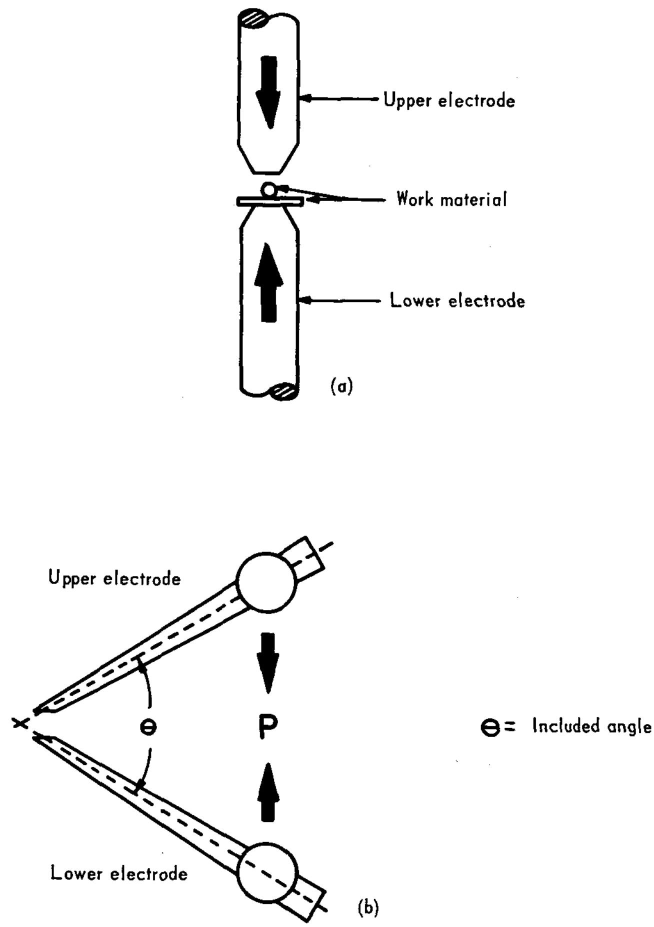


FIGURE 8.—Creating heat balance.

Selection of an electrode of proper composition solves only half the problem. The electrode configuration or design must also be given consideration as it will depend upon the geometry of the materials to be welded, accessibility of the materials, flexibility of the leads, and the weld schedule requirements.

The preferred welding configuration is the vertically opposed electrode (fig. 9a) because the force exerted on the materials is one of pure compression which reduces tip wear and wear on the weld head. In addition, straight shank, flat tip electrodes are easier to fabricate and maintain. However, in most cases, the straight electrode cannot be used because of accessibility problems. When this problem arises,



a. Straight electrode configuration.
b. Offset electrode configuration.

FIGURE 9.—Electrode configurations.

the offset configuration is used. (See fig. 9b.) In using an offset electrode, consideration must be given to the included angle, shank diameter, and face area. Two requirements must be fulfilled when using the offset configurations: sufficient cross-sectional area must be provided to allow proper current flow; and the electrode shall be mechanically strong enough to transmit the pressure requirements. Improper design can cause excessive lateral movement of the electrodes, imparting a shearing movement to the interface of the weld joint during follow-up. Obviously, this produces a poor weld joint.

The electrode design may also include a protective coating on the electrode shank, such as ceramic or polyurethane, as a safeguard against shorting component leads to the electrode. The protective coating may also be color coded to aid in identification of the electrode.

Chapter 5

INTERCONNECTING AND COMPONENT LEAD MATERIALS

During the development of the welding technique for application to the packaging of electronic parts, the problem of compatible materials appeared. Component manufacturers supply a variety of component lead materials in many diameters. To further complicate the problem, many lead materials are plated or dipped to resist corrosion or to obtain some unique characteristic. It became necessary to standardize component lead materials and diameters as much as possible.

GENERAL CONSIDERATIONS

The properties of materials which have the greatest bearing on weldability are resistivity, thermal conductivity, and melting point or hot working temperature. R. D. Enquist of Hughes Aircraft Company cites the following equation as an index of weldability:

Equation

$$W = \frac{R}{FK_t} \times 100$$

W = Weldability Index
R = Resistivity (Ohm-centimeters)
F = Melting Point (Degrees Celsius)
K_t = Thermal Conductivity

The equation is an empirical one and as such does not yield valid results in all cases. Table 2 is a tabulation of weldability indices for various materials. The results are fairly consistent with the practical experience gained from welding experimentation. In particular, notice that the weldability index of copper is the lowest in the table, indicating that it is the most difficult to weld. Because of this difficulty, copper component leads have been eliminated from the standards.

Materials available for welding may be categorized with respect to composition of the material. The four basic categories are:

a. Pure or semi-pure metals.
b. Alloys.
c. Plated metals.
d. Clad metals.

Materials in all of these categories have been used for interconnection and component leads. Some of the more common materials which have been used are listed in table 3.

TABLE 2.—*Weldability Indices of Materials*

Category	Metal	Resistivity (ohm-cm.)	Melting point (degrees Cel.)	Thermal conductivity Kt*	Weldability index
Ferrous Metals	Iron	9. 71	1539	0. 18	3. 51
	Cobalt	6. 24	1495	. 165	2. 46
	Nickel	6. 48	1455	. 22	2. 15
Light Metals	Aluminum	2. 655	660	. 53	. 76
	Magnesium	4. 46	650	. 38	1. 80
Conductive and Noble Metals.	Copper	1. 673	1083	. 94	. 16
	Silver	1. 59	960	1. 0	. 17
	Gold	2. 19	1063	. 71	. 29
	Platinum	9. 83	1773	. 17	3. 26
	Palladium	10. 8	1554	. 17	4. 10
Refractory	Molybdenum	5. 17	2625	. 35	. 56
	Tungsten	5. 5	3410	. 48	. 34
	Tantalum	12. 4	2996	. 13	3. 19

*Calorie centimeters/second/square centimeter/degree Celsius (taken from "Metallurgy of Electronic Welding" by R. D. Enquist).

Materials are plated or clad to improve their ability to resist corrosion or to obtain some unique characteristic. In general, clad materials, such as copper clad steel, are avoided because of inconsistencies and non-uniformities of the clad material. A notable exception to this is the use of dumet. Since the weldability of the material can be directly related to the cladding material or the base material, depending on the thickness of the cladding, these non-uniformities tend to cause differences in the requirements of the weld system parameters of pressure and energy.

TABLE 3.—*Materials Used for Electronic Welding*

Category	Commercial name	Basic composition (percent)	Plating	Clad	Used for
Pure and semi-pure.	*Nickel "A".	99% Nickel.	----------	----------	Interconnecting material and component leads.
	Copper----	Copper----	Solder or tin dipped.	----------	Component leads.
Alloys---	*Kovar (Rodar).	17% Co, 29% Ni, 53% Fe.	Usually gold.	----------	Transistor and diode leads.
	Alloy 90---	12% Ni, bal. Cu.	----------	----------	Interconnect material.
	Alloy 180--	22% Ni, bal. Cu.	----------	----------	Interconnect material.
Clads---	*Dumet---	42% Ni, 58% Fe.	Usually gold.	Copper sheath.	Component leads.
	Copperweld.	Steel core--	----------	Copper---	Interconnect material.
	Nickel clad copper.	Copper core.	----------	Nickel---	Interconnect material.

*Standardized Materials.

A gold plating over a nickel strike has proven to be advantageous when welding kovar and dumet leads. In addition to corrosion resistance, the gold plating has been found to increase the weldability of the materials. In the use of kovar, the gold plating appears to expand the iso-strength region in which acceptable welds can be produced.

STANDARDIZED MATERIALS

The materials which have been selected for use in welded modules were chosen as the result of vast experimentation and experience. Although it is possible to weld other materials, such as copper, the resulting bond is usually weak when compared to the bond obtained using standard weld materials. In addition to the strength factor, the choice of materials was made in consideration of problems encountered by component manufacturers, particularly transistor and diode producers who have a hermetic seal problem.

The standardized weld materials used for component leads are high purity nickel, kovar, and dumet. The material used for interconnecting mediums is high purity nickel. Detailed requirements for these materials may be found in appendix A.

Nickel appears to be the most desirable metal for interconnection purposes. It is compatible with the other materials and welds readily to itself.

Kovar and dumet have been used for a number of years as component leads. Both are used in diodes and transistors to ease the glass to metal hermetic seal problem.

Components with weldable leads are available from leading manufacturers. However, in many cases, the procurement order must specify that weldable leads are desired, and usually there is an increase in the price.

POLARITY SENSITIVE COMBINATIONS

Two problems frequently occur when dissimilar metals are welded together. The first problem, heat unbalance, was discussed earlier. The second problem is polarity sensitivity.

Polarity sensitivity refers to the adverse effects to welds when the improper electrode polarity is used. Since current flows in only one direction in the secondary of the weld transformer, the electrodes can be assigned a definite polarity. In the case of welding certain dissimilar combinations, a definite decrease in weld strength is noticeable if correct polarity is not observed. The cause of this phenomenon has not been ascertained.

The materials which have been determined to be polarity sensitive when welded to a nickel ribbon are copper and kovar. In most cases, a reduction in pull-strength of greater than 50 percent is noticeable. There are undoubtedly other combinations which exhibit this phenomenon. However, because of the standardization of materials, the only combination of concern is the nickel to kovar weld. Table 4 is a comparison of pull strenghts for normal and reversed polarities of nickel ribbon (0.010 in. x 0.047 in.) welded to gold-plated kovar (0.017 in. dia.).

TABLE 4.—*Effect of Reversed Polarity*

Energy	Pressure	Pull strength	
		Normal polarity nickel (−) kovar (+)	Reversed polarity nickel (+) kovar (−)
7.5 ws	4 pounds	19. 0	6. 5
7.5 ws	do	19. 7	8. 0
7.5 ws	do	18. 8	7. 8
7.5 ws	do	20. 3	7. 6
7.5 ws	do	19. 5	7. 1
7.5 ws	do	19. 0	8. 3
7.5 ws	do	19. 0	8. 8
7.5 ws	do	19. 6	7. 9
7.5 ws	do	18. 9	7. 1
7.5 ws	do	18. 3	7. 7
Average		19. 2	7. 7

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Chapter 6

WELD INSPECTION

Welds must be examined to detect any condition or defect that may impair the reliability of the connection. Examination of the weld may be made by performing a destructive or nondestructive inspection.

NONDESTRUCTIVE INSPECTION (VISUAL INSPECTION)

The visual inspection is the only method available at the present time to nondestructively evaluate the weld connection. In some cases a defective weld can be detected by the unaided eye, but in most cases an optical aid is required to detect minute defects. To evaluate the welds visually, inspection criteria and standards must be established to serve as a guide for the inspector. The inspector must also exercise his own judgment based on experience in marginal cases.

Every weld in a module must be visually inspected using an optical aid having a minimum magnification of 30 power. This necessitates that a module be inspected at selected points during fabrication as some welds are inaccessible upon completion of the package. Upon completion of the package, all accessible welds should be re-examined to determine if any damage has resulted from handling during fabrication.

Visual inspection criteria are based on the external characteristics of a weld which are detectable by optical magnification.

An unacceptable weld, from the visual inspection standpoint, is one which exhibits one or more of the following characteristics:

a. Open Weld
b. Offcenter Weld
c. Cracked Weld
d. Deformed Weld
e. Metal Expulsion
f. Splattering and Fragments
g. Blow Hole
h. Pitted Weld
i. Excessive Surface Fusion
j. Excessive Setdown
k. Insufficient Weld

Open Weld

A point where a weld has been attempted but no fusion or forging action has occurred due to misfire of the welding machine, or a point where a weld is specified by drawing but has been overlooked by the operator. When microscopic examination leads the inspector to suspect an open weld, it is permissible to "probe" the connection. However, force to the weld must be applied with caution to avoid stressing the weld.

Offcenter Weld

A weld in which either or both of the materials were not centered between the electrodes. This type weld normally causes excessive metal expulsion. In some cases, if high electrode force has been used, the offcenter weld can be detected visually by the location of the indentations of the electrodes. (See fig. 10.)

Cracked Weld

Any weld which exhibits a crack in the weldment or adjacent to it. Cracks normally appear along the fillet or across the weld area. (See fig. 11.) Cracks are caused by excessive pressure and/or heat.

Deformed Weld

A deformed weld is one in which the diameter or thickness of either of the materials has been reduced by more than 50 percent or the total reduction of both materials is greater than 35 percent. Deformation is caused by excessive pressure and/or heat. (See fig. 12.)

Metal Expulsion

A weld which exhibits either excessive bulging of metal at the interface, "splashed" metal deposits on the adjoining element, or fragments extending from the weld interface. Metal bulging (sometimes referred to as distortion) is not metal expulsion in the true sense of the word. It appears along the interface of the weld and is the result of too much pressure. The excessive pressure forces the material to form a bulge while it is in the plastic stage. (See fig. 12.) A slight amount of bulging is not considered to be detrimental.

Splattering and fragments of metal extending from the weld zone are actual cases of mteal expulsion and occur because of excessive pressure and/or heat. (See fig. 13.)

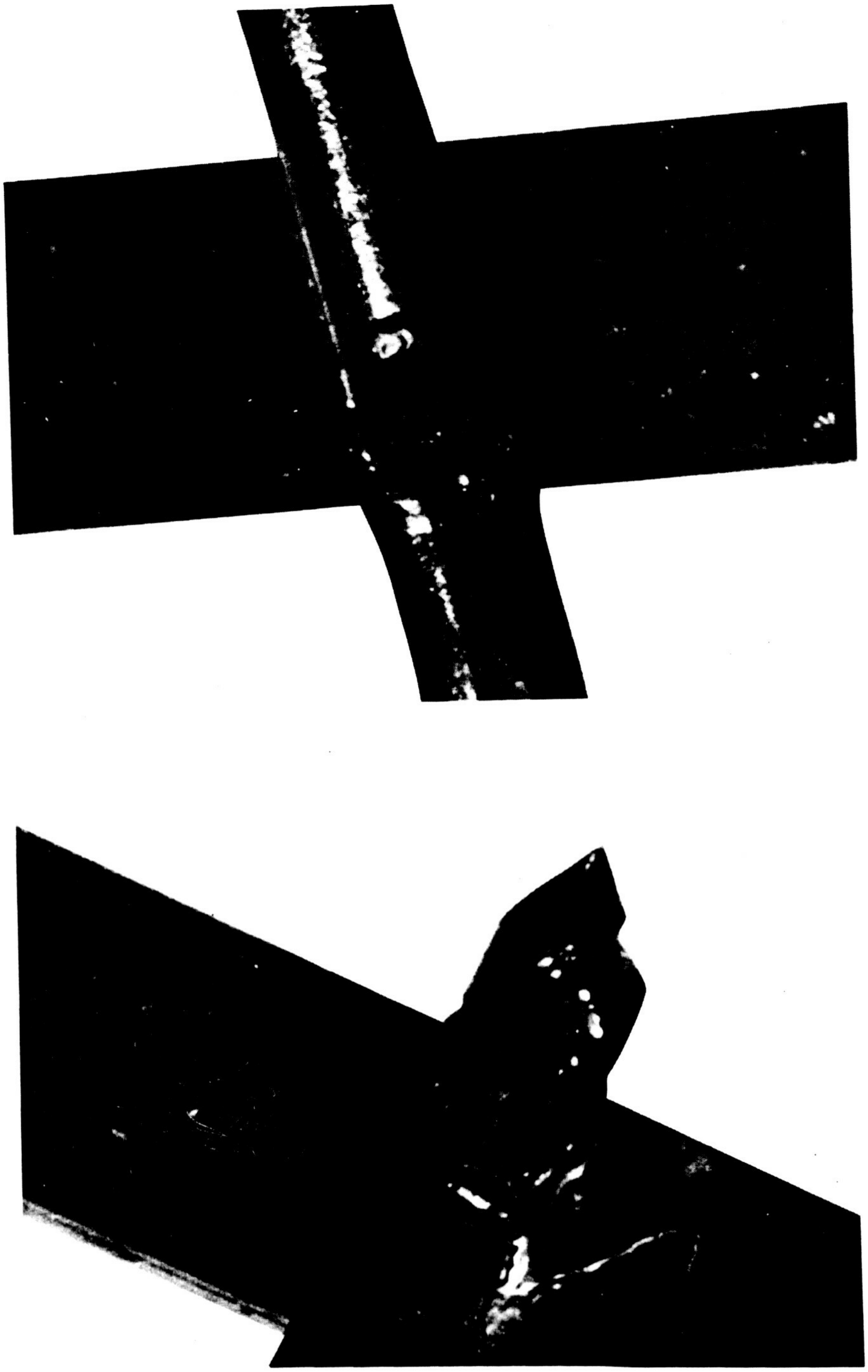

FIGURE 10.—Offcenter welds.

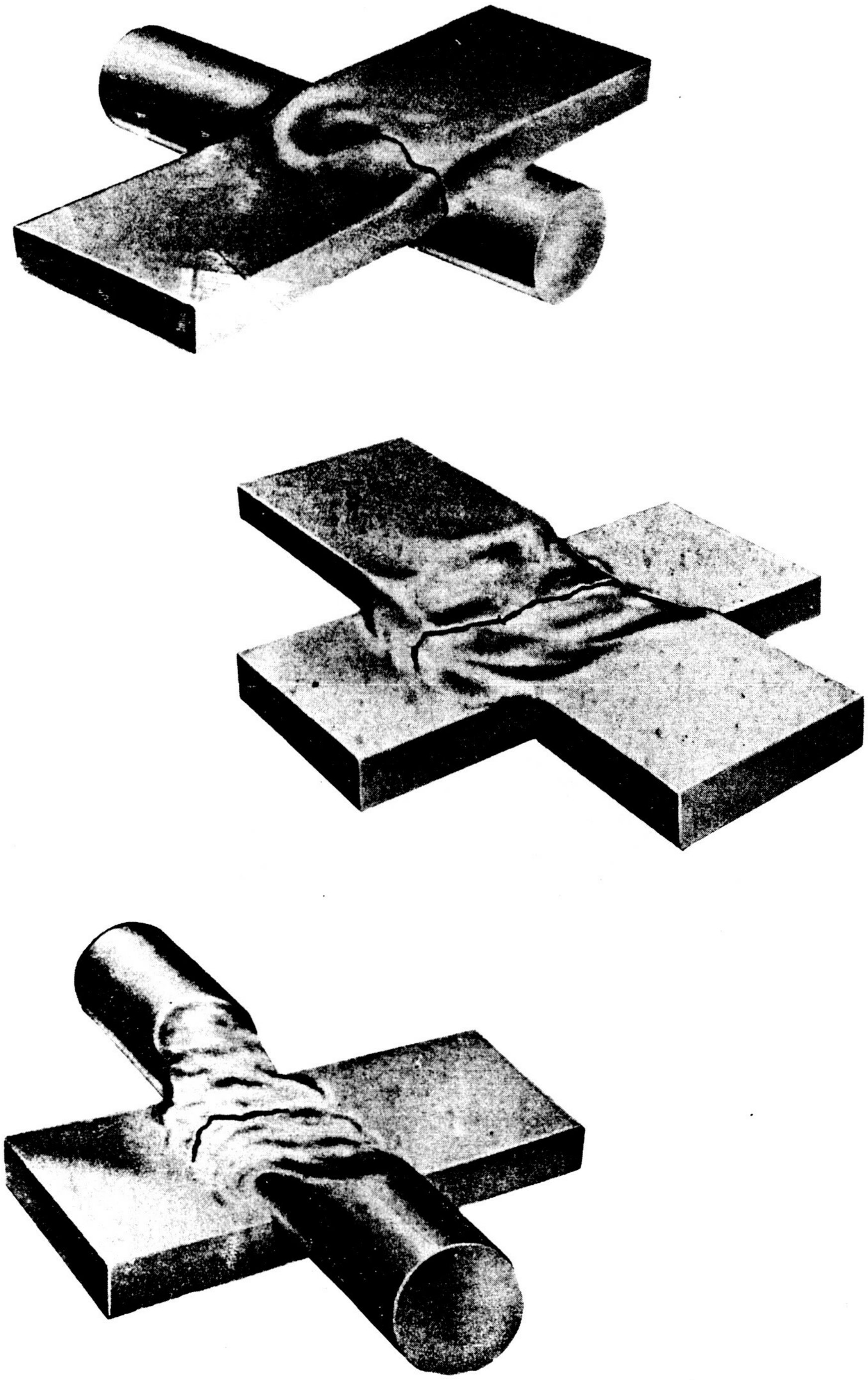

FIGURE 11.—Cracked welds.

FIGURE 12.—Deformed weld.

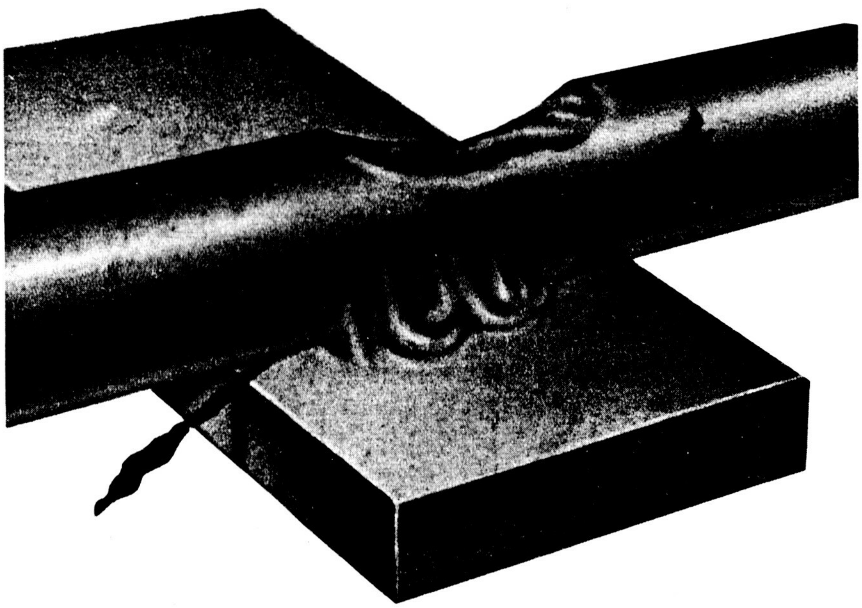

FIGURE 13.—Splashed weld.

Blow Hole

A weld in which holes are evident, usually along the fillet. These holes are readily detectable under magnification. Blow holes result from the formation of a gas pocket in the weld zone which reaches such high internal pressures that metal is expelled. (See fig. 14.)

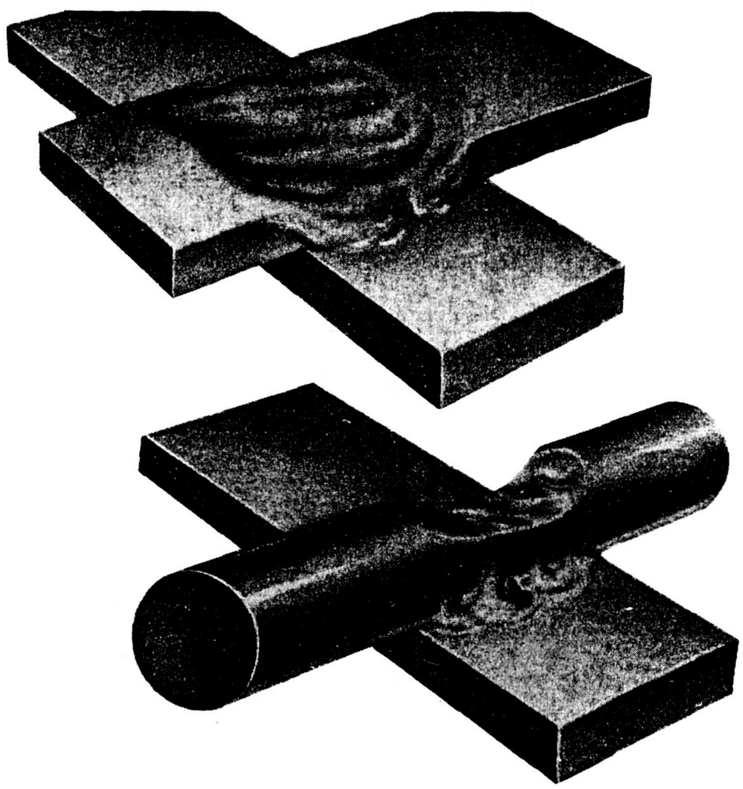

FIGURE 14.—Blow hole.

Pitted Weld

A weld that exhibits "pits" in either or both of the materials being joined. In certain cases when surface fusion occurs, the molten metal adheres to the electrode (termed "Sticking"). As the electrode force is released, the material which has adhered to the electrode is pulled from the parent metal, resulting in a rough and pitted surface. (See fig. 15.)

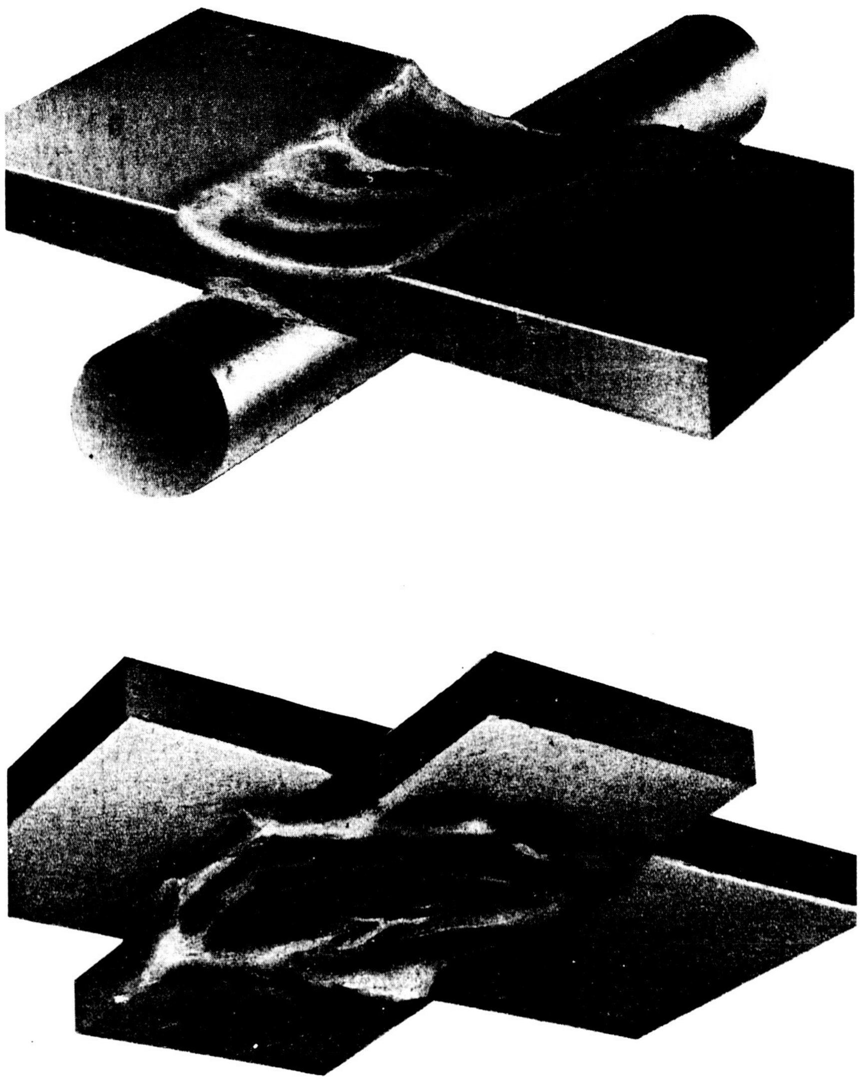

FIGURE 15.—Pitted welds.

Excessive Surface Fusion

A weld in which the weld material has melted to an excessive degree at the point of interface with the electrode. A contact resistance exists at this point. (See zones 2 and 6, fig. 4.) If this resistance is higher than that at the weldment interface, or if proper heat balance has not been attained, the contact area will melt.

In certain cases, a small amount of surface fusion cannot be avoided. However, it is desirable to keep this to a minimum, preferably below 10 percent of the lead diameter. (See fig. 16.)

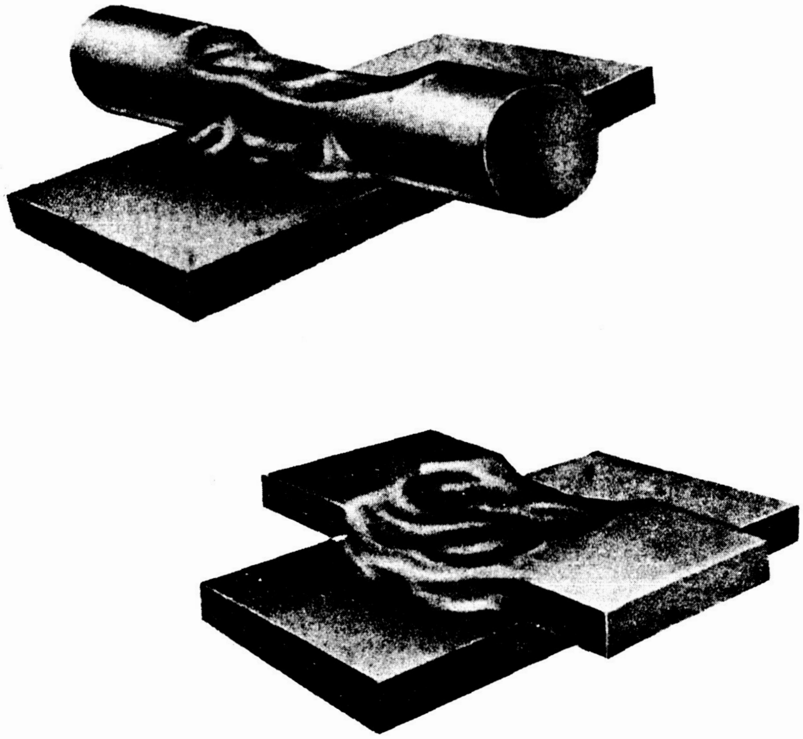

FIGURE 16.—Excessive surface fusions.

Excessive Setdown

Setdown is the degree to which the thinner of the materials being joined is physically forced into the thicker material. It is expressed in percent, and is shown in figure 17. Setdown should not exceed 50 percent.

Insufficient Weld

An insufficient weld is one in which fusion or forging action has occurred, but not to the extent that minimum weld strength requirements can be met. It is extremely difficult to detect, and if this condition is suspected to exist, a number of samples should be obtained from the machine which produced the questionable welds

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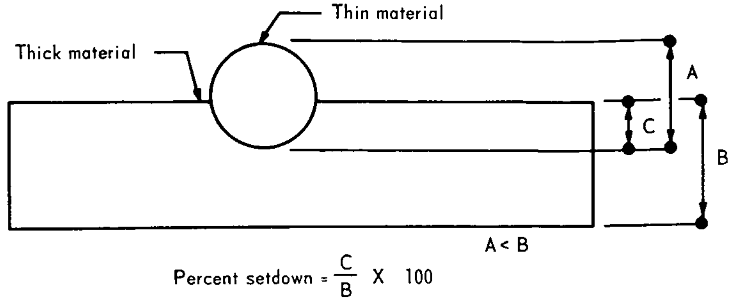

FIGURE 17.—Setdown.

and pull-tests made. In certain cases, as in round materials welded to rectangular materials, it may be possible to detect insufficient welds by observing the fillet at the interface. The fillet should be evident at least along 75 percent of the interface.

Normally, a defective weld will exhibit two or more of the above conditions. For example, figure 10 is an offset weld in which a weld splatter is evident. Figure 12 exhibits cracks, excess surface fusion, and excess metal bulging.

DESTRUCTIVE INSPECTION

Destructive inspection is made by either a pull-test or metallurgical test. Pull-testing is time consuming and expensive, and it destroys the product. Nevertheless, it is the only method available at the present time for obtaining quantitative data about the parameters of a weld. Since this method is destructive, it must be used only on a sampling basis.

The pull-test is commonly referred to as a tensile test of the weld. The test consists basically of pulling the weld apart by applying a tensile force of opposite direction to each lead. Besides the tensile force, there is also a shear force, and, in some instances, a torsional force applied at the weld joint. Figure 18 illustrates the three methods which are in use by various companies for pull-testing welds. Method A of figure 18 is the preferred pull-test method. This method applies an additional stress to the joint.

Method A is referred to as the torsion-shear method of pull-testing. This method places a torsional force in addition to a tension and shear force on the weld. In general, this method results in pull-test strengths which are much lower than the results obtained by either of the other methods. Mechanically locked interconnections are detected by the torsion-shear method, whereas they may not be detected by other methods.

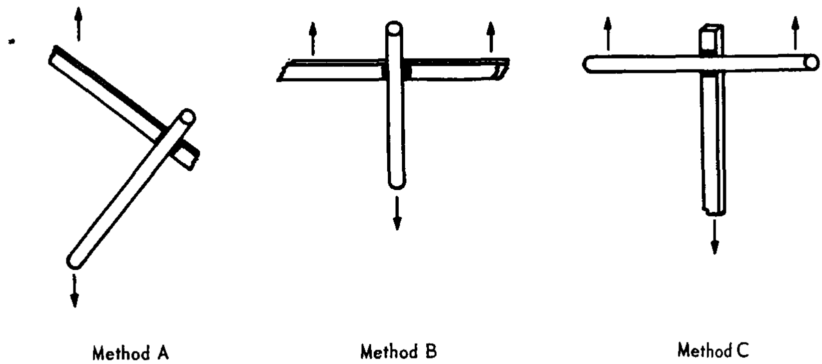

FIGURE 18.—Methods of pull testing.

The significance of this test is that a quantitative analysis of the weld strength may be obtained and used as a basis for determining optimum welding machine settings. Once the machine has been set, periodic pull-tests performed on samples taken from the production line can be evaluated and the results used as an in-process check.

METALLURGICAL EXAMINATION

Metallography is the only feasible analytical technique available for evaluating the quality of a weld. Metallographic examination reveals the interior of the weld, enabling the observer to determine what type of weld has been made, the amount of fusion present, and any defects present within the weld. However, it takes a trained and experienced metallographer to interpret the photomicrographs.

Before the interior of the weld can be observed, the sample must be encapsulated in a rigid substance and then subjected to a series of grinding and polishing operations. These operations leave a free surface and a disturbed crystalline layer above the basic metal for examination. The free surface and disturbed crystalline layers are removed by an etching process which, if done properly, will reveal the true structural characteristics of the weld.

Improper control or selection of welding variables can be readily determined by metallographic analysis. Such conditions as excessive or insufficient pressure or energy, heat unbalance, or combinations of these have a direct effect on the metalurgical appearance of the weld.

Insufficient pressure is sometimes evidenced by metal expulsion and sometimes by the appearance of a heat affected zone (HAZ) at the point of contact of the electrode. Metal expulsion is usually prevalent when welding heat is high and the foregoing pressure is not great enough to retain the molten metal. This condition may also be a result of poor head inertia. The heat affected zone results because the low pressure of the electrodes creates a high contact resistance at the electrode and material interface.

Excessive pressure is evidenced by metal expulsion which results in blow holes. In this case, the pressure is so great that it expels the molten material from the weld zone.

Insufficient heat results in the lack of fusion and, consequently, a poor weld joint. (See fig. 19.)

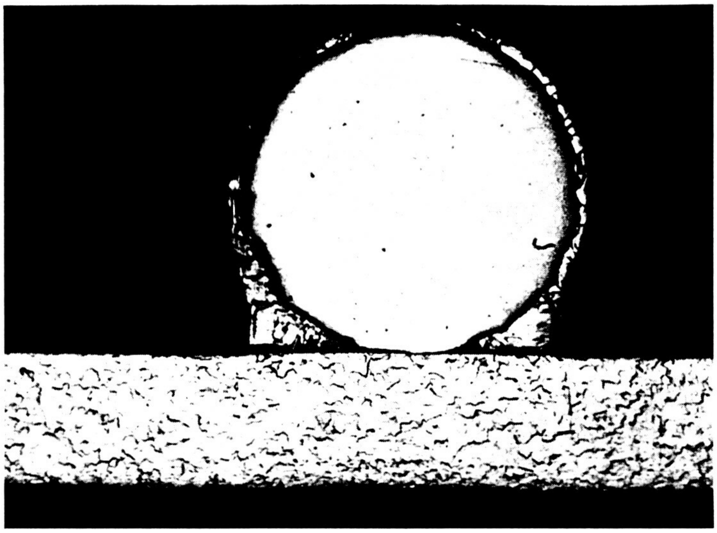

FIGURE 19.—Lack of fusion caused by insufficient heat.

Excessive heat can cause excessively large nuggets (over penetration) which, in extreme cases, extend the full width of the material. Over penetration is undesirable since the recrystallized nugget lacks ductility. Excessive heat also contributes to metal expulsion, gas pockets, and shrinkage cavities. Figure 20 is a photomicrograph of a weld containing shrinkage cavities.

The nugget of a fusion type weld should exhibit equal penetration and be free of porosity, inclusions, blow holes, and shrinkage cavities. Penetration is defined as the depth to which the fusion extends into the material and should be at least 20 percent of the material thickness. Figure 21 illustrates proper penetration.

Improper heat balance can, in many cases, be detected by the presence of a nugget existing within one of the materials. (See fig. 22.) Figure 22 (top) shows a nugget that is contained within the clad

FIGURE 20.—Excessive heat and pressure resulting in shrinkage cavities.

of an inter-connecting material. Improper heat balance can be solved by methods discussed previously.

A sound weld in which the clad has been broken through and proper heat balance has been attained is shown in figure 23 (top).

It has been found, in certain cases involving welding of solder coated leads, that a resistance solder joint was produced by the weld process, rather than a true weld. A similar situation exists when welding dumet to an inter-connecting material. Here, the copper sheath melts and forms a brazed joint. Both of these conditions have been detected by metallographic analysis.

The value of metallographic analysis is obvious and should be performed on welds produced at machine settings to verify the adequacy of the weld parameters to produce reliable welds. However, metallographic analysis and interpretation should be performed by a qualified metallographer or metallurgist.

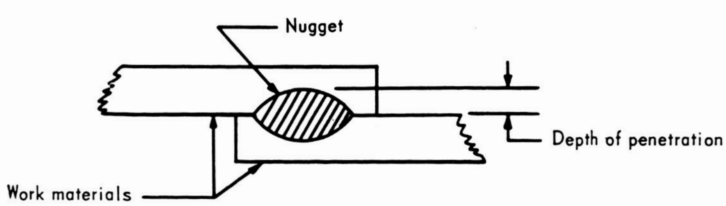

FIGURE 21.—Proper penetration.

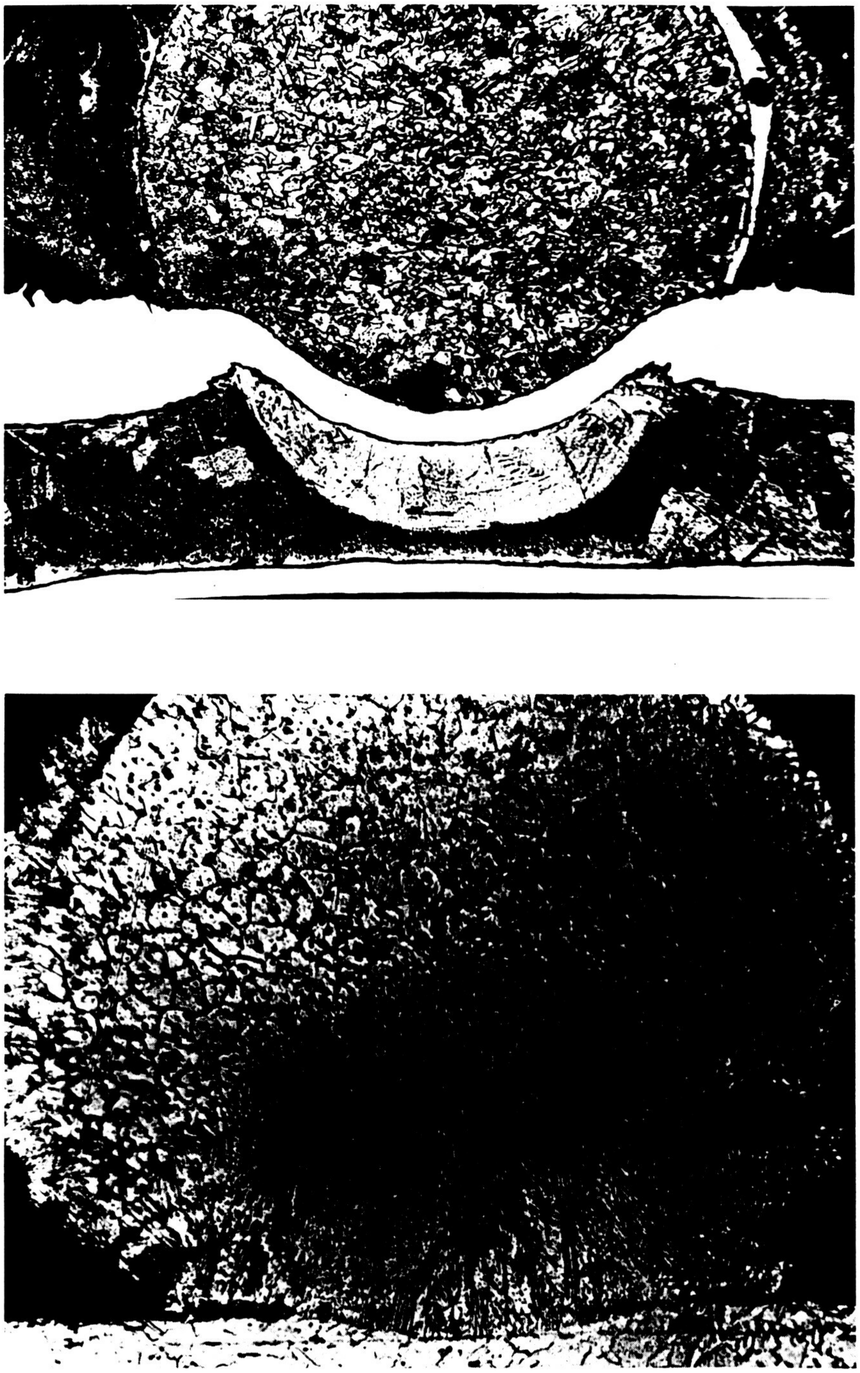

FIGURE 22.—Improper heat balance (photographs courtesy of Sippican).

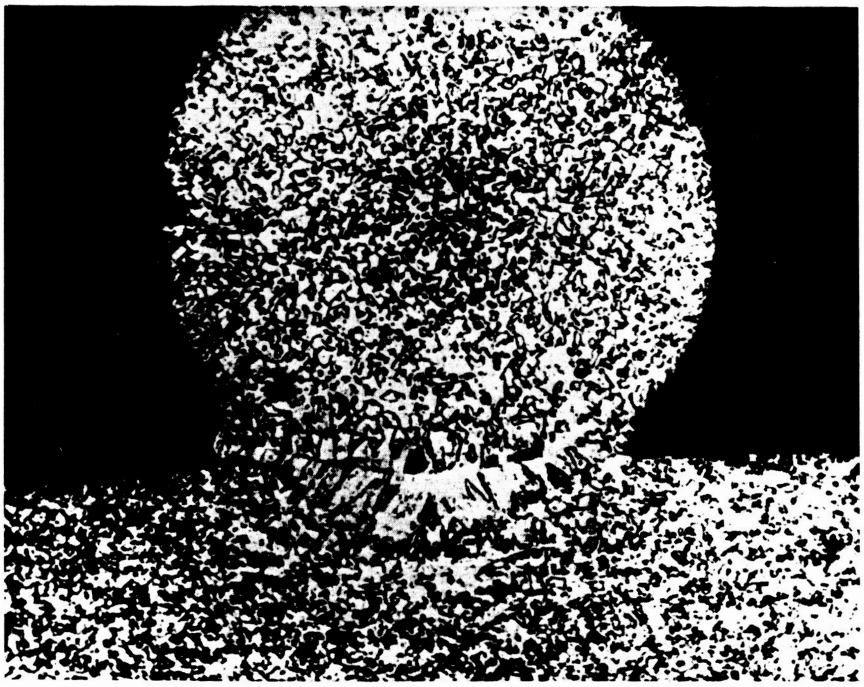

FIGURE 23.—Proper heat balance (photographs courtesy of Sippican).

Chapter 7

PROCESS CONTROL

Effective process control is primarily the joint responsibility of manufacturing and quality control. However, the nature and variables of the welding process dictate that other organizations be aware of the variables of the welding process and of how they can contribute in order that process control can be attained. (See charts 1 and 2.)

Design organizations in particular should be familiar with the welding process. Package design concepts must conform to applicable specifications, and, in addition, the design should be such that it can be manufactured. In their haste to miniaturize packages, many designers forget that adequate clearance must be available for the electrodes during manufacture. The designer or packaging engineer usually furnishes the weld sequence list, which necessitates that he be familiar with the welding process. It is also the designer's responsibility to specify components, and, hence, he should be familiar with the standardized component lead materials. Every effort should be made to procure components with weldable leads.

Procurement departments should be familiarized with the weldable lead problem and cautioned about substituting, to economize during procurement of parts. Weldable leads generally cost a little more, and delivery time in many cases is slightly longer. However, procurement of weldable lead components will more than offset these disadvantages by the reduction of manufacturing and process control problems.

EQUIPMENT

Equipment variables must be specified prior to the establishment of weld schedules, and after a satisfactory weld schedule has been established, these equipment parameters must be held constant. The parameters of prime importance are power supply capacitance, weld pulse characteristics, and weld circuit resistance. Normal maintenance and calibration is, of course, required to keep the equipment in satisfactory operating condition and should be performed in ac-

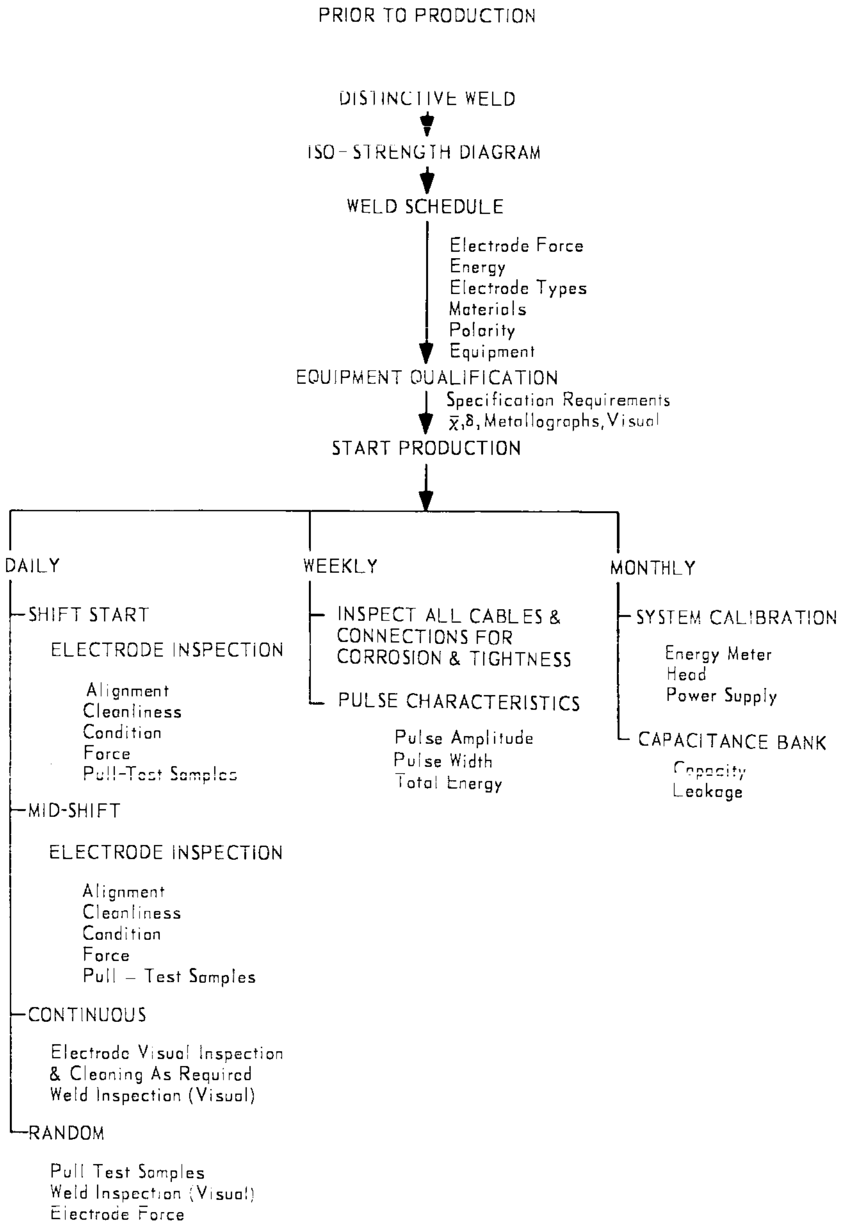

CHART 1.—*Elements of process control.*

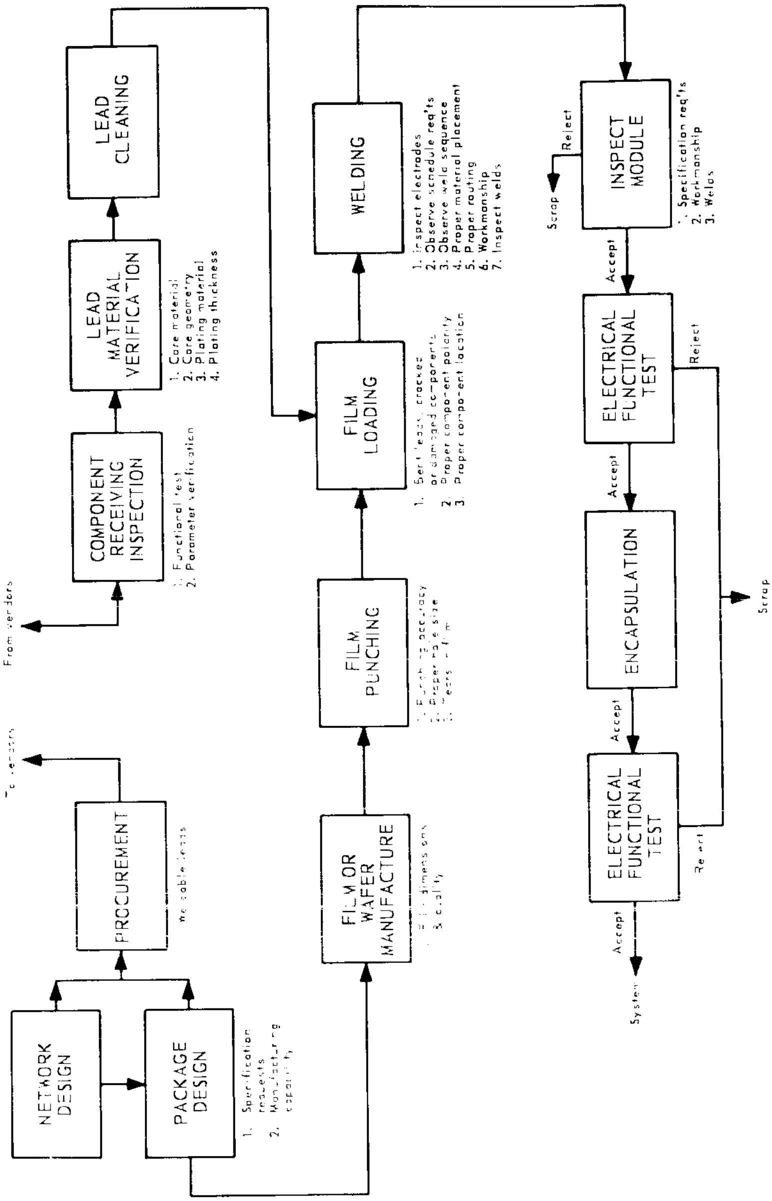

CHART 2.—*Welding process flow chart.*

cordance with the equipment manufacturer's recommendations. Generally, equipment manufacturers' procedures apply only to static conditions, and it is necessary to supplement their recommendations with additional tests.

POWER SUPPLY CAPACITANCE

The capacitance of the energy storage bank should be measured on a periodic basis; the interval between measurements depends on the workload of the equipment. Capacitors, like other electronic components, age with use and change characteristics. A change in capacitance produces a corresponding change in the energy delivered to the weld zone. This change in energy is not detected by the voltmeter because the meter is reading only the voltage stored on the storage bank.

Capacitance of the storage bank should be measured by a capacitance bridge with an accuracy of at least ±3 percent. The measurement of capacitance involves an a.c. signal, and, hence, attention must be paid to the frequency of the signal. The selection of the frequency to be used should be correlated with that of the manufacturer of the equipment, providing that the manufacturer performs this measurement. Usually a frequency of 60 cps is specified.

In addition to the measurement of capacitance, it is also desirable to measure the dissipation factor and leakage current of the bank.

WELD PULSE CHARACTERISTICS

The characteristics of the secondary voltage pulse can be utilized for maintaining equipment and process control efficiency. The two pulse characteristics of importance are pulse amplitude and pulse duration. These characteristics can be seen by the use of a standard resistor and an oscilloscope. The standard resistor is used to load the weld circuit in lieu of the weld materials. The resistor is normally connected across the electrode holders from which the input to the oscilloscope is taken. A memoscope (or a standard oscilloscope) may be used as the display device and a photograph taken of the wave form. The standard resistor may be a calibrated meter shunt or bar stock, but it should have a resistance of from 50 to 200 micro ohms to simulate the resistance of a typical weld. The characteristics of the secondary voltage pulse can be utilized for maintaining equipment and process control efficiency.

The energy delivered to the weld circuit is represented by the area bounded by the pulse curve. Two completely different pulse shapes can contain the same amount of energy, but produce entirely different welds. Figure 24 illustrates two pulses, both having the same energy content. However, two entirely different welds will be produced by the pulses. Pulse A will produce a strong, reliable weld. Pulse B will produce no weld at all because the pulse amplitude is not great enough to provide sufficient heat to cause a weld.

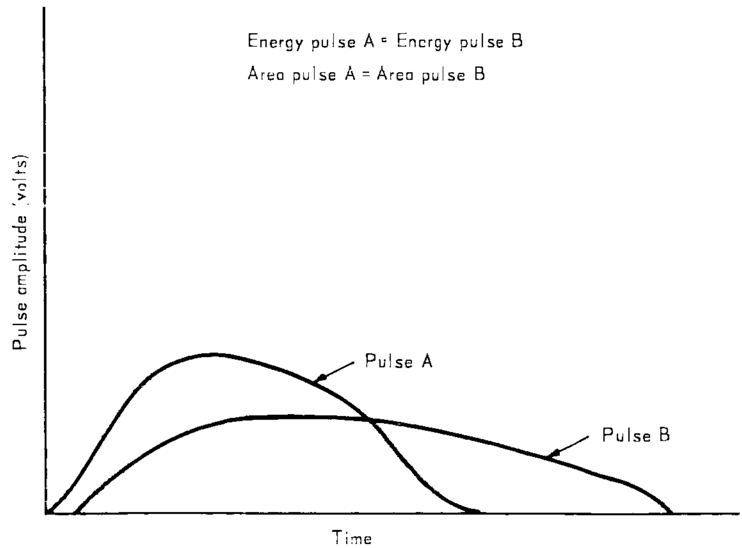

FIGURE 24.—Energy pulse curves.

In some cases, photographs of pulses are taken during the production of a weld. These photographs are then used for process control. In these cases, the scope input is taken directly from across the weld.

There are several devices available from welding equipment manufacturers that are specifically designed for measuring these pulse characteristics.

WELD CIRCUIT RESISTANCE

It was shown in chapter 3 that the weld circuit is basically a series circuit consisting of a number of resistances. A change in any of these resistances produces a corresponding change in the energy delivered to the weld zone.

Once a welding system has been set up and iso-strength diagrams established, all of the following parameters should be maintained constant:

a. Interconnecting cabling length, size, and spacing.
b. Electrode holder length and size.
c. Electrode material, included angle, tip size, and shape.

Some of the resistances of the weld circuit are contact resistances and are susceptible to change as a result of loose or corroded connections. Therefore, connections should be inspected periodically for corrosion and tightness.

MATERIALS AND COMPONENTS

As mentioned earlier, the designers must specify the material to be used in the package. This is the first step in controlling materials and components.

Procurement is the second step in the control of materials and components. Every effort should be made to procure only those materials standardized and specified in appendix A for component leads and interconnection materials. In a survey of component manufacturers, most companies contacted replied that weldable materials must be specified in the procurement order. This points up the fact that procurement personnel must be aware of the specifications for weldable materials.

RECEIVING INSPECTION

Upon receipt of an order of components, the components should be processed through an inspection for defects. The inspection should include:

1. A visual examination for nicked leads, gross defects in platings, broken glass seals, and such.
2. A functional type test to determine that the parameters of the device are within the limits of the procurement specification.
3. An analysis of the composition and geometry of the component lead material, including plating material and thickness.

The determination of the composition of the component lead material may be made by chemical analysis or by taking samples of the lead material and welding them to an interconnecting material in accordance with the applicable weld schedule. For example, assume that an order of components has been received that should be equipped with kovar leads as specified on the procurement order. It is assumed that the leads are kovar and a number of sample leads are taken from the components. These leads are then welded to an interconnecting material in accordance with the applicable weld schedule, the welds are pull-tested, and the pull-test results are compared with the strength specified by the weld schedule. If the results are comparable, it can be assumed that the leads are kovar.

Copper leads are the most common type available. A very quick check to determine whether the components have weldable leads or not is to place a magnet in close proximity to the lead. If it is copper, which is very hard to weld, the lead will not be attracted to the magnet. All of the standardized weldable materials are highly magnetic and will be attracted to the magnet. However, many other materials which are not on the standardized materials list are magnetic, and this simple test should be used only to indicate that the component lead is not copper.

HUMAN FACTORS

Although the welding process reduces the role of the assembler in making electrical connections, it does not eliminate the human entirely. There are systems available which reduce the assembler's role to a minimum by use of semi-automatic and tape-programmed welding equipment, but these have not received wide acceptance in industry. Qualified personnel are essential to realize success in any technical process, and proper attention must be given to the working environment.

PERSONNEL

The nature and requirements of the weld process have resulted in three general categories of personnel that are directly concerned with process control: the welding line supervisor, the assembler/operator, and inspection personnel. The distinction among them is primarily made by the responsibility assigned to them and the level of knowledge of the weld process which is required of them.

WELDING LINE SUPERVISOR

The welding line supervisor supervises the operation of the welding line and is responsible for the following:

a. Machine setup (energy level and electrode force).
b. Process control.
c. Sampling.
d. Electrode condition.
e. Maintenance of equipment.
f. Weld schedules.
g. Calibration of equipment.
h. Inspection.

The welding supervisor should have a sound background in the theoretical and practical aspects of welding.

ASSEMBLER/OPERATOR

The assembler/operator actually assembles the packages and operates the welding machine and its associated equipment. The responsibilities and functions of the personnel in this category should be limited to:

a. Assembly of basic elements of the package.
b. Welding.

c. Superficial cleaning of electrodes.
d. Inspection of welds.

The nature of training for assembler/operators should primarily be practical rather than theoretical. However, they should be exposed to the very basic theories. Appendix B presents an outline delineating a suggested course of instruction for assembler/operators.

INSPECTION PERSONNEL

Inspection personnel should receive the same training as assembler/operators, with additional emphasis on the theory of resistance spot-welding.

WORKING ENVIRONMENT

The working environment should be regulated with regard to temperature and humidity not only for the comfort of the welding line personnel but to aid in process control.

Many companies have found that when the relative humidity rises above 55 percent, the welding equipment performs eratically. No satisfactory explanation has been offered to account for this phenomenon. It is recommended that companies regulate the relative humidity of the welding line area to 55 (± 5) percent.

The temperature of the welding line area should also be held constant at a comfortable working level. Capacitance increases with temperature, and, if extreme temperature fluctuations exist, a wide variation in weld quality results.

Other working environment factors that should be given consideration are lighting, equipment layout, and pleasant surroundings.

IN-PROCESS CONTROL

In-process control is an element of over-all process control and refers to control activities during process operation. In-process control can be best maintained by utilization of well trained and alert inspectors who can recognize defective welds and poor weld system performance.

Visual inspection of all welds produced in the first step in the line of in-process control measures. This type inspection is supplemented by pull-testing welds at periodic intervals. Weld samples taken at random from the line and pull-tested provide a check on individual operator performance.

Strength criteria of pull-tested welds and their visual characteristics should be observed and recorded during the construction of the iso-strength diagram and the weld system verification. This information must be maintained on file for reference.

WELD SCHEDULE RECORD

The determination of optimum welding parameters for any given, fixed set of conditions was discussed previously. These optimum values of energy and electrode pressure are the schedule for the given materials. The iso-strength diagram is often referred to as the weld schedule because the schedule is determined from it. The iso-strength diagram and/or weld schedule is perhaps the most important tool in the maintenance of process control because it sets up the initial criteria with regard to weld strength for a particular material combination. In addition to the weld strength, such characteristics should be recorded during the construction of the iso-strength diagram to aid inspectors and manufacturing personnel in determining when the process is in control. Actual weld samples should be maintained on file with the iso-strength diagram for future reference.

ELECTRODE INSPECTION AND MAINTENANCE

An important step in the control of the welding process is the inspection and maintenance of the electrodes. Nomenclature for the electrodes is illustrated in figure 25.

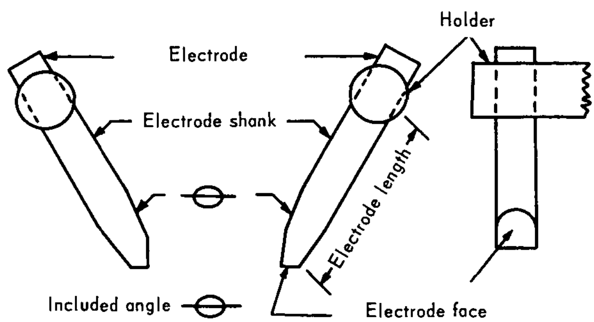

FIGURE 25.—Electrode nomenclature.

Electrodes should be inspected at the beginning of each shift for condition and alignment. After the shift has started, the electrodes should be inspected at half-hour intervals, or more frequently, if necessary, for conditions such as tip pickup, tip wear, pitted tips, and excessive face growth. Visual inspection of the electrode face is facilitated by the use of a dental mirror.

Tip pickup is encountered frequently and consists basically of material that is picked up during the weld process. During the weld cycle, fusion can occur at the interface of the electrode and the work material. The extent of tip pickup depends on the degree of fusion at this interface. In extreme cases of tip pickup, a condition known as "sticking" occurs, where material is fused (stuck) directly to the electrode. Tip pickup is directly affected by the type of materials being welded, and the condition of the weld circuit interfaces and their respective resistance. This was considered in our discussion of heat balance. If proper heat balance is attained, tip pickup will be at a minimum.

Electrode length, included angle, parallelism of tips, and proper mating of the tips should be verified prior to start of each shift. Verification of the included angle is conveniently made with the aid of an alignment fixture, as shown in figure 26. Figure 27 illustrates proper electrode alignment and mating. Figure 28 depicts improper electrode alignment.

Electrode pits occur when arcing takes place. The arc makes small pits in the electrode face. Since pits are difficult to remove under normal cleaning procedures, the pitted electrodes should be replaced and dressed later.

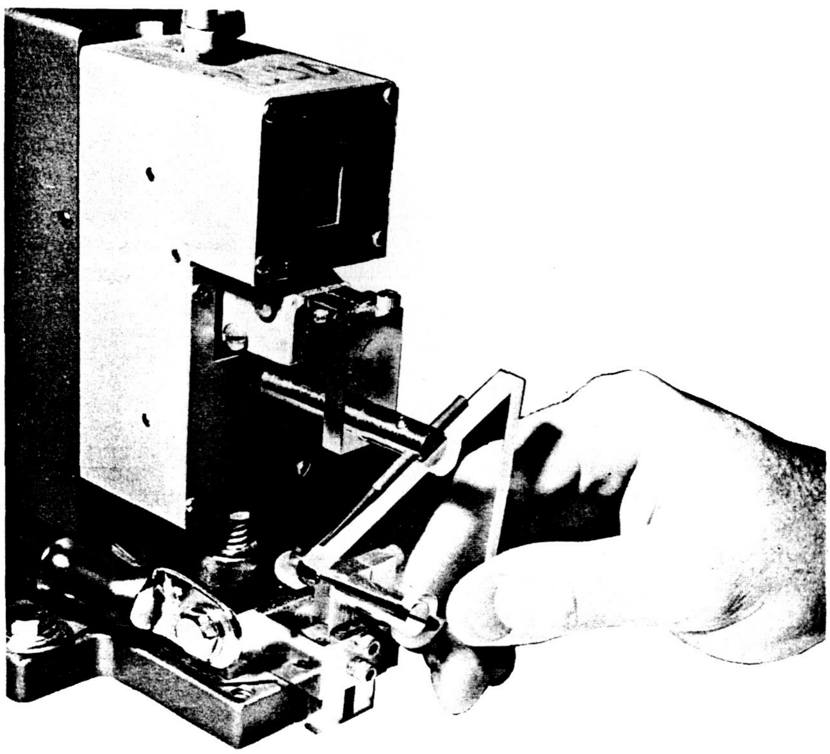

FIGURE 26.—Electrode alignment fixture.

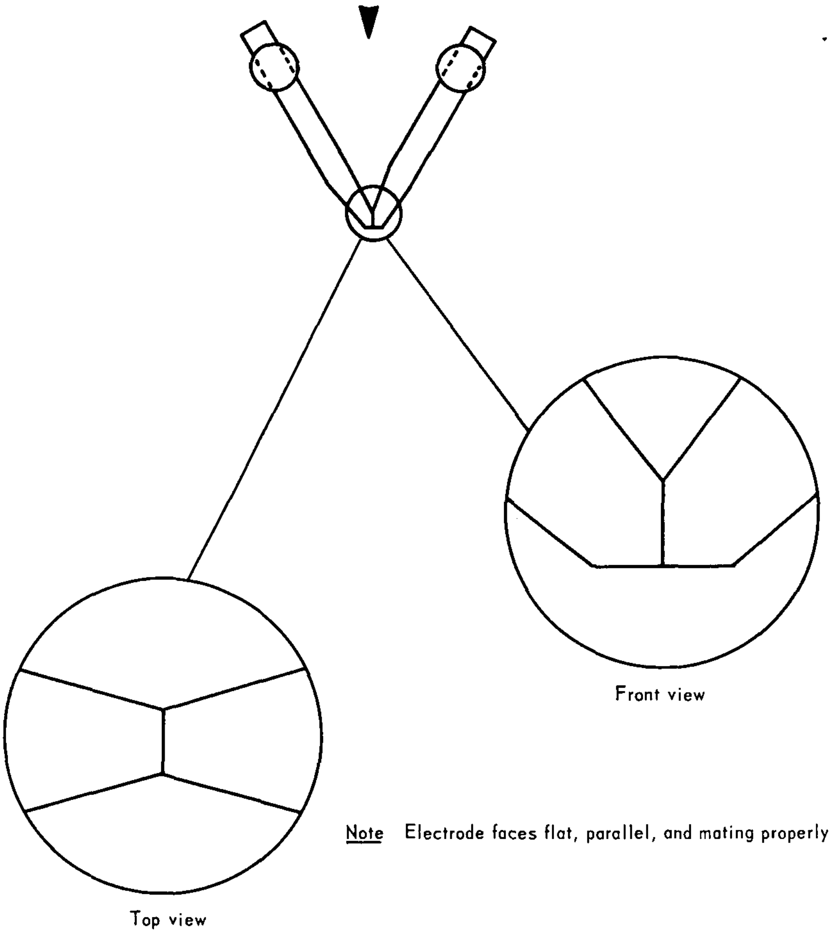

FIGURE 27.—Proper electrode alignment.

Electrode dressing should be accomplished with #600 (or finer) grit paper. *Under no circumstances should files be used.* Dressing is accomplished by: (1) inserting the dressing tool between the electrodes; (2) applying electrode force; and (3) rotating the dressing tool so that the electrode faces become burnished. When tapered electrodes are dressed, there is an increase in the electrode face area. The pressure and current density at the electrode/material interface are both decreased as the electrode face area increases due to cleaning. If the face area increases excessively, it could cause inferior welds.

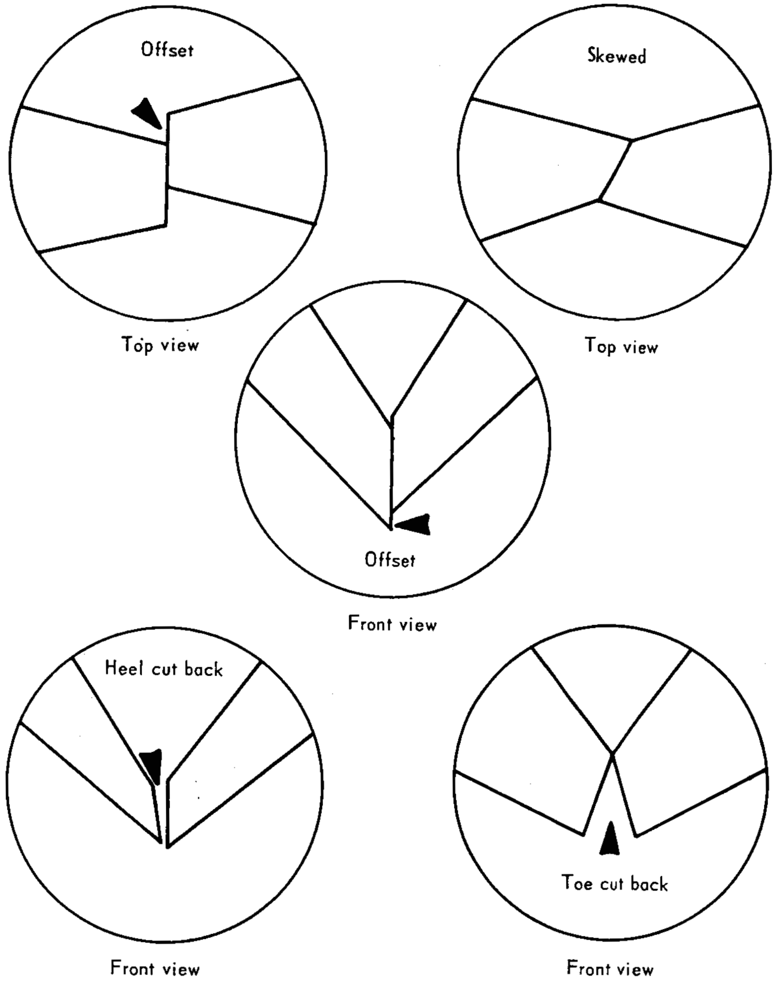

FIGURE 28.—Improper electrode alignment.

WELD SEQUENCE LIST

The weld sequence list defines the order by which the welds of a package will be performed. It provides an orderly and efficient method of weld programming which serves to reduce the probability of weld defects and missed welds.

The weld sequence list is generally prepared by the packaging design engineer and should include a consideration of the accessibility of weld points as the package progresses through the manufacturing process. The damage that can occur to semiconductors under certain circumstances should also be taken into consideration. An example of such damage can be found in a low resistance closed loop circuit where the final weld closes the loop, as shown in figure 29. When conditions similar to this have occurred, it has been found that semiconductors have been damaged.

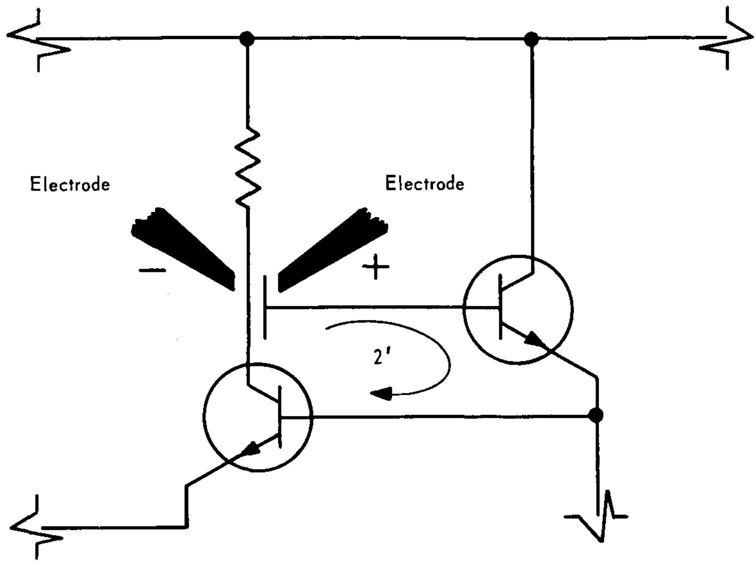

FIGURE 29.—Shunting of current through semiconductor.

In general, weld sequences should proceed from one end of the run to the other, making all intermediate welds in order as shown in figure 30a. If this procedure is not followed, excess interconnection material may be entrapped between welds. (See fig. 31.) Another acceptable sequence is to make the initial weld in the center and then proceed toward each of the final welds in the run as shown in figure 30b.

PACKAGING METHODS

There are many different methods which are used to package electronic components, using welding as the interconnection medium. Most of the packaging techniques result in the components being stacked; hence, they are referred to in general as "cordwood" packaging.

"Cordwood" packaging results in a three-dimensional package as opposed to the more common two-dimensional package obtained by using printed circuit boards. It is primarily because of the "cordwood" technique that a substantial increase in component density can be achieved.

The following paragraphs are intended to familiarize the reader with the more popular methods being utilized to package electronic components using welded connections as the interconnection medium.

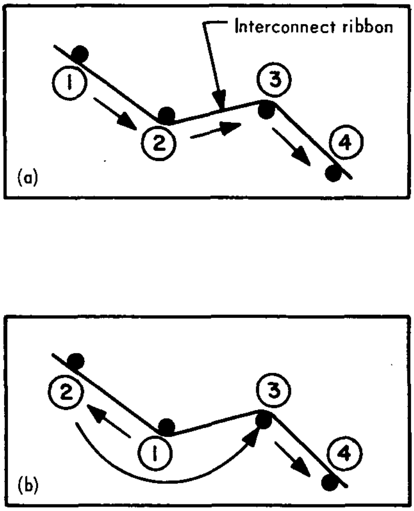

FIGURE 30.—Proper weld sequences.

MATRIX PACKAGING

The matrix approach of packaging electronic components centers around a pre-assembled wiring pattern based on a right angle grid system. The assembly consists of two sets of parallel wires separated by an insulating film such as mylar. (See fig. 32.) The mylar film serves as an insulator and prevents the wires from shorting to each other. The film has a pattern printed on it which shows the interconnection wiring of the package.

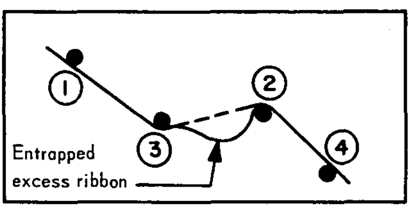

FIGURE 31.—Improper weld sequence.

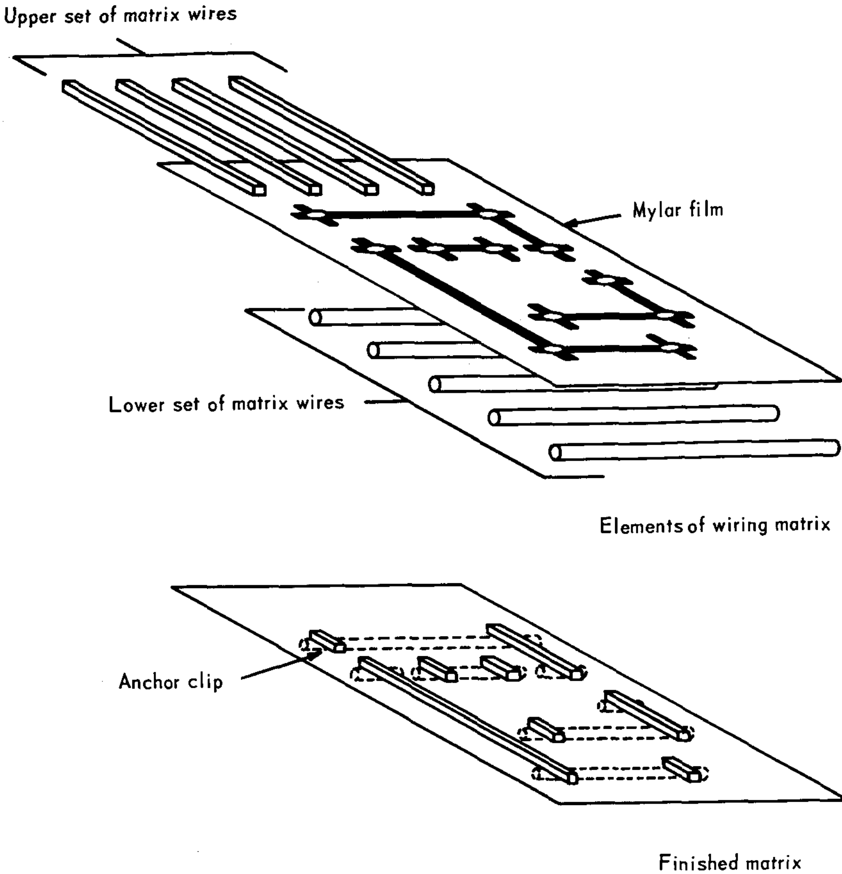

FIGURE 32.—Matrix packaging.

Guide holes are punched along each edge of the film through which the sets of wires are passed. Other holes are punched at places wherever a wire of the upper set is to be welded to a wire of the lower set. After the mylar film has been loaded, welds are made at designated spots by a vertical head. The excess wires are then clipped out, leaving the desired wiring pattern. When a long section of wire is encountered, a small section is welded at the opposite end to aid in retention of the run and is referred to as an "anchor clip". The interconnection matrix is now ready to be welded to the functional components.

The component leads are inserted through punched holes in the mylar film so that the component lead is adjacent to the interconnection wire of the wiring matrix. When all components have been loaded, the component leads are welded to the interconnection wiring.

Complex packages of high density may require several matrix layers.

The advantage of using the matrix approach is that the interconnection wiring can be verified for accuracy prior to the welding of any components into the package. Simplification of job inspection is a very definite advantage of utilizing films with printed interconnecting patterns. However, since the components are oriented on a grid system, the package form factor is often restricted.

POINT-TO-POINT PACKAGING

As the name implies, the point-to-point method of packaging utilizes an interconnecting ribbon or wire which is routed between the two points to be connected by the most direct route. The components to be interconnected are positioned between two insulating films in such a way that the component leads protrude through. Interconnections are then made by routing the interconnection material between the points to be connected by the most direct route. Figure 33 illustrates this technique.

It is possible with this technique to use pre-printed films which are desirable for inspection purposes. The task of inspecting and verifying wire routing becomes much easier with pre-printed films as a guide.

FIGURE 33.—Point-to-point packaging.

HEADER PACKAGING

The header approach is one of the simplest and cheapest methods available for packaging components. However, the more complex the network to be packaged, the more undesirable this method becomes. Thus, its use is generally restricted to very simple networks.

The header is composed of a base plate with pins mounted on it. The package build-up generally proceeds around the header, the header pins being connected to the component leads by the interconnecting material. (See fig. 34.) Besides being limited to simple networks, the probability of shorted circuitry is greater with this type of packaging.

The particular method of packaging employed depends on many factors and will generally be chosen by the design and/or packaging engineer. No matter which method is chosen, documentation and drawings must be prepared to assist the manufacturing personnel in the assembly of the package. An essential element of this documentation is the weld sequence list.

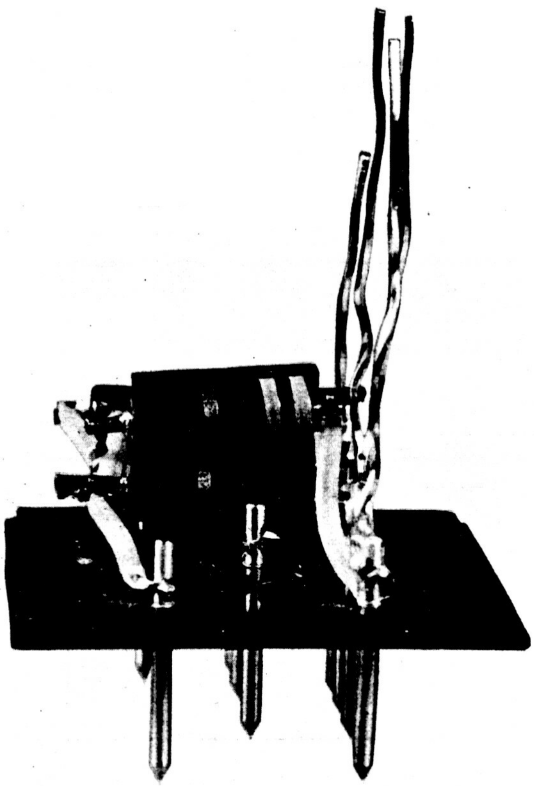

FIGURE 34.—Header packaging.

WELDING TECHNIQUE

The following comments about welding technique are considered to be important since they are the most frequently violated. There are many finer points involved in constructing a welded package; however, most of these must be learned from experience. The particular points to be discussed are placement of materials, module positioning, and head actuation.

PLACEMENT OF MATERIALS AND MODULE POSITIONING

The materials to be welded should be placed between the electrodes in such a manner that they form a 90-degree angle, as shown in figure 35. Each of the weld materials should be placed so that it is centrally located on the face of the contacting electrode. Care must be taken to ensure that the materials are placed properly with regard to weld schedule requirements. For instance, if the weld schedule requires a kovar lead to be placed next to the movable electrode and a nickel ribbon next to the stationary electrode, this requirement must be observed to obtain a good weld.

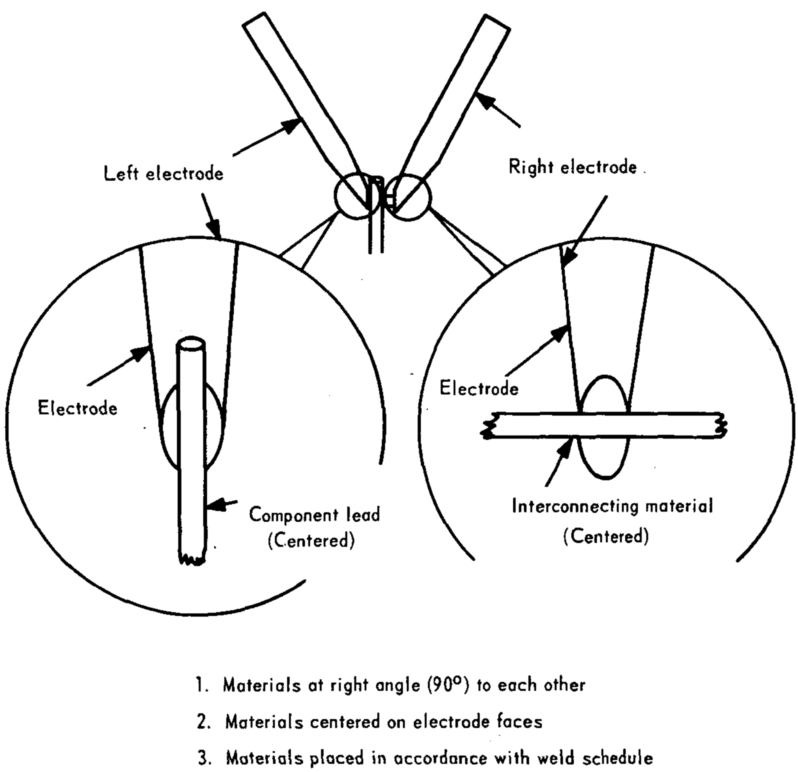

FIGURE 35.—Proper placement of materials.

Certain other precautions must be taken with regard to material placement to ensure the production of adequate welds. Some packaging configurations can result in component leads, other than the one being welded, shorting to one of the electrodes. (See fig. 36.) If conditions are right, this could result in a poor weld. This shorting can be prevented by coating the electrodes with a dielectric material or by clipping the offending component lead prior to welding.

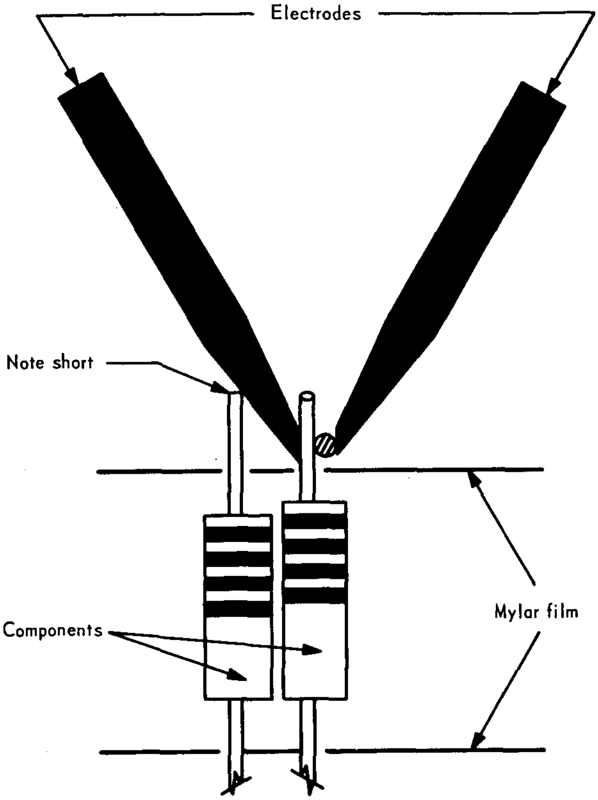

FIGURE 36.—Shorting component leads.

Bend radii of interconnecting materials should be kept to a maximum. It is possible, if a very small bend radius is used, that the interconnecting ribbon could come into contact with the opposite electrode, thus shunting some of the weld current away from the weld zone and producing an inferior weld. Even if a shunt condition does not exist, small bend radii are undesirable because more contact area exists at the weld interface which reduces the contact resistance and the current density at this point, both contributing to production of an inferior weld. Figure 37 illustrates proper and improper techniques.

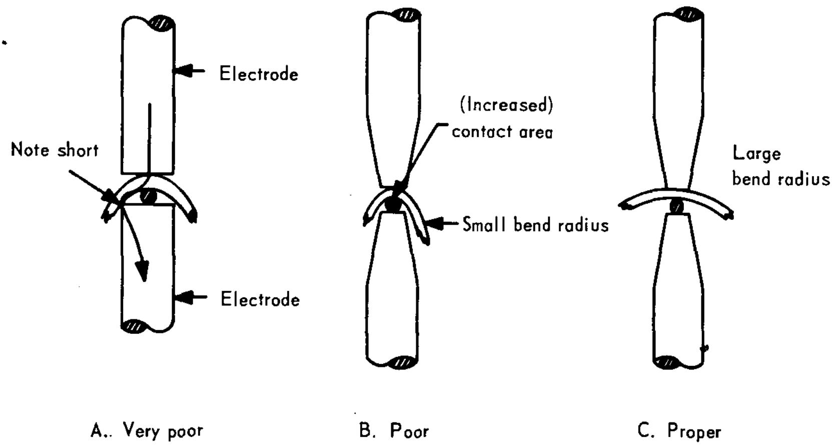

FIGURE 37.—Bend radii of interconnecting materials.

If the electrode face is smaller than the material which it is facing, the entire electrode should be centered on the material as shown in figure 38.

The module should be held in such a manner that the component lead is parallel to the face of the electrode before the electrodes are brought together. Figures 39A and 39B illustrate the proper technique and the improper technique. The correct method eliminates bending of the lead due to the electrode force and tearing of the mylar film. If a very small electrode force is being used, the machine may discharge before the component lead makes full contact with the interconnecting material, which results in a poor weld.

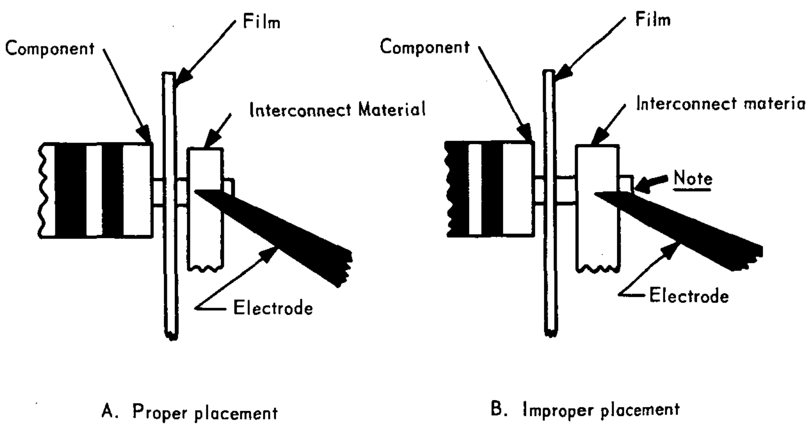

FIGURE 38.—Electrode centering.

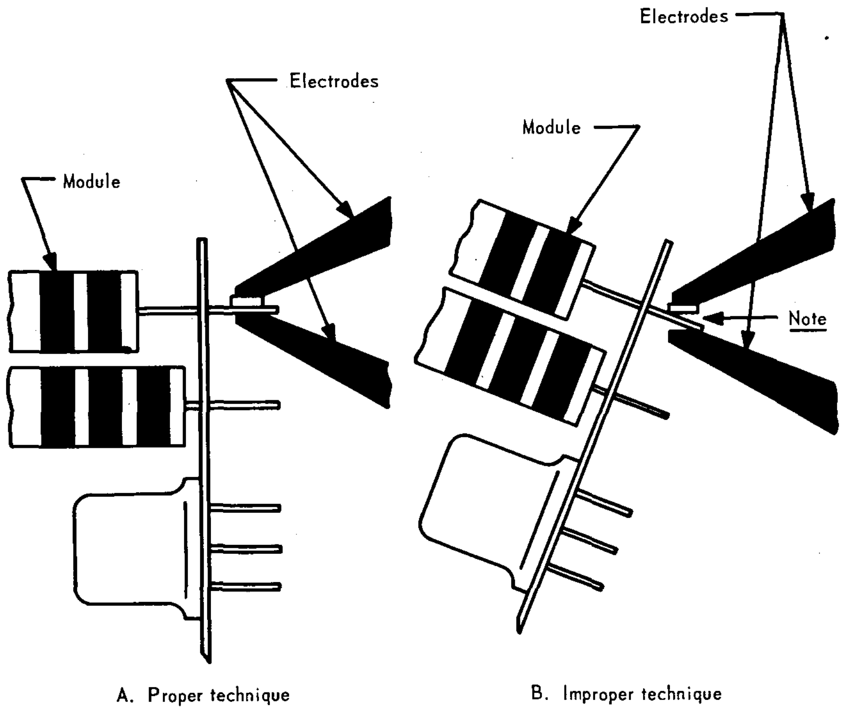

FIGURE 39.—Module positioning.

HEAD ACTUATION

Head actuation refers to the mechanical application of electrode pressure needed to provide the necessary forging action. As previously discussed, electrode pressure is one of the prime variables of the welding process; hence, its application must be made properly. Other terminology by which head actuation is referred to within the welded package industry is "striking the weld" and "electrode firing".

Assuming that the electrodes are aligned and cleaned properly, and that the materials have been placed between the electrodes properly, the operator is now ready to "fire the electrodes". Head actuation should already have been started in applying slight electrode pressure to the materials to aid in proper placement. Electrode pressure should then be *slowly* increased at a constant rate until the weld has been accomplished.

The electrode firing can be detected by one or more of the following events:

a. The micro-switch actuation has been heard. In certain types of equipment, the "click" is very difficult to detect, whereas in others, a very audible sound is produced.

b. A decrease in pressure may be evident when welding certain material combinations because of the set-down of the materials. This condition is best detected by experience.

c. In certain cases, a slight arc may be evident; however, do not confuse this with spitting or splatter.

As soon as it has been determined that the electrodes have fired, pressure application should cease and the electrodes allowed to return to their normal position.

It is imperative that the electrode force be applied in a slow, continuous manner and at a constant rate. Rapid actuation and/or stomping on the foot pedal results in excess pressure and over travel, thus producing inferior welds. Weld consistency depends upon proper actuation of the weld head, using the same amount of pressure each time.

GLOSSARY OF WELDING TERMS

Accelerator: A chemical used to speed up a reaction or the curing of a plastic. Often used along with a catalyst, hardener, or curing agent. Sometimes used to describe the curing agent.

Acceptable Weld: A weld which is at or near the minimum criteria limit (not the most desirable condition). Occasionally used to describe all welds from specification minimum to optimum. (See also **Good Weld.**)

Active Device: A device whose output is dependent on a source of power other than the main input signal. (Examples: amplifier, transistor, electron tube.)

AC Welder or Welding: A machine or method in which the amplitude and duration of the welding pulses are synchronized with the incoming AC line voltage and controlled in relation to amplitude and duration.

Alloy: A material having metallic properties and consisting of two or more elements, of which at least one is a metal. It is considered by some that the elements must be completely miscible in the liquid state; others apply the term alloy even when liquid miscibility is only partial.

Annealed Metal: A metal in its softest condition or temper.

Annealing: A heating and a cooling operation of a material in the solid state. Annealing usually implies a relatively slow cooling. The purpose of such a heat treatment may be to:

a. Remove stresses.
b. Insure softness.
c. Alter ductility, toughness, or electrical, magnetic, or other physical properties.
d. Refine the crystalline structure.
e. Remove gases.
f. Produce a definite microstructure.

Arc Percussive Welding: A type of welding in which the materials to be welded are separated by a gap, an arc is struck across the gap which melts the surfaces of the materials, and the materials are simultaneously brought together. (See also **Pulse Arc Welding.**)

Assembly: A number of parts or sub-assemblies or any combination thereof. joined together to perform a specific function. (*Note:* The distinction between an assembly and a sub-assembly is not always exact; an assembly in one instance may be a sub-assembly in another where it forms a portion of an assembly.)

Blow Hole: A small hole or cavity in the vicinity of the weld caused by gas entrapped during solidification.

Blow-Out: The "explosion" of a joint during the welding cycle, usually caused by improper weld energy or electrode pressure settings.

Bonded: Joined by atomic attraction or by intimate contact with a melted filler material (as in a brazed joint).

Braze Weld: A type of weld resulting from the presence of a lower melting point filler material in the joint, wetting and usually penetrating into the structure of each member being joined and with little or no fusion of the basis materials. The filler material is generally the plating or cladding on one or both of the basis materials.

Brazing: Joining metals by fusion of nonferrous alloys that have melting points above 800° F, but lower than those of the metals being joined.

Brittleness: A tendency to fracture without appreciable plastic deformation.

'B' Stage: An intermediate stage in the curing of a thermosetting resin where the material is solid at room temperature but can be heated and caused to flow. Compression and transfer molding materials generally supplied in the 'B' stage.

Burned Weld: A weld characterized by a charred discoloration of the metal(s) being welded and generally accompanied by other defects such as cracks and gross melting. A result of excessive weld energy being applied to the joint.

Bus: Wire or ribbon (usually nickel) used for interconnecting component leads.

Butt Weld: Welding edges or ends together.

Card: In Planar welding, the single-plane group of components while held in their assembly or welding fixture.

Case: A plastic or metal container which forms the outside dimensions of a module. Sometimes used to conduct heat away from critical electronic parts or to perform radio frequency (RF) shielding. Usually filled with embedment compound. (See **Pot.**)

Cast: To embed a component or assembly in a liquid resin, using molds which separate from the part for re-use after the resin is cured. (See **Embed, Pot.**)

Catalyst: A chemical that initiates or accelerates a chemical reaction (the curing of a resin), but which does not become a chemical part of the final product.

Circuit: One or more components joined together by connections to perform an electronic function.

Circuit Element: Any portion of an electronic circuit which is considered as a non-divisible entity in design analysis or application.

Circuit Module: A circuit module is an encapsulated, throw-away group of electronic components, generally stacked side by side in cordwood fashion and electrically connected by means of point-to-point or matrix wiring. The circuit module usually contains from three to twelve transistors and associated components. Power and logical connections to other circuit modules are brought out at one or both ends of the module or through terminal pins.

Clad or Cladding: A relatively thin surface of a different material which has been fused to, and made integral with, the basis metal core.

Coalescence: The union of particles of a dispersed phase into larger units, usually effected at a temperature below the fusion point.

Cold Weld: The joining together of two metals (without an intermediate material) by the application of pressure without the addition of heat.

Component: Any one of the parts that make up a piece of electronic equipment. A functional unit treated as an entity in the fabrication of a circuit. May be an active or passive device.

Component Parts Density: The number of component parts per unit volume (cubic inch or cubic foot). (See also **Volumetric Efficiency.**)

Connection: That part of a circuit which has negligible impedance and which joins components together.

Constant Force Chart: See **Weld Profile Chart.**

Conventional: Usual; the common method prior to the advent of the newer art and practices under discussion.

"Cordwood" Technique: The arrangement of components within a module so that the component bodies are parallel and in close physical proximity to one another.

Core: The inner, or basis, material after cladding.

Cracked Weld: A small separation at the weld in one or both of the materials being welded, caused by excessive heat and/or pressure inducing stresses in the material.

Crossover: The point at which two conductors, insulated from each other, cross, and a connection is made.

Curing Agent: See **Hardener.**

DC Welder or **Welding:** A machine or method in which the incoming AC line voltage is raised and rectified and the energy is stored in a capacitance bank. Activating a switch discharges this voltage through a transformer, the secondary of which contains, as part of its circuit, the electrodes and the materials to be welded.

Deformation: Change in shape of the materials being welded because of electrode pressure; usually a flattening effect.

Dielectric Strength: The capability of an insulator to withstand an applied voltage without breaking down and conducting current.

Diffusion Bond: The migration of the atoms of one or both metals across the welded joint interface, generally occurring when joining two similar or compatible metals of different alloy composition.

Discoloration: A localized change in color on some materials in the weld area because of the heat of the weld energy dissipated.

Discrete Component: A component which has been fabricated prior to its installation.

Electrode: That portion of the resistance welding circuit which is in contact with the materials being welded. It transmits weld force and carries current to the work. Is a means of providing proper heat balance (by altering its composition) when materials being welded are varied.

Electrode Alignment Gage: Permits positive alignment of beveled electrodes used with pincer weld heads.

Electrode Force: Unless otherwise specified, means static force:

Static: The mechanical force between the electrodes under welding conditions with no current flowing and no mechanical movement of the electrodes. Also called *clamping force.*

Dynamic: The (varying) mechanical force between the electrodes during the actual welding cycle.

Electron Beam Welding: The process of using a focused beam of electrons to heat materials to the fusion point.

Element: Any portion of an electronic circuit that is considered as a non-divisible entity in design, analysis, or application.

Embed: (*1*) To encase a component or assembly in some material (generally plastic). The embedment material occupies a large part of the package volume and conforms to the shape of the mold or case.

(*2*) The distance one material enters or is entered by another while being welded. Usually expressed as percentage (original thickness minus thickness remaining divided by original thickness).

Encapsulate: To coat a component or assembly in a conformal or thixotropic coating by dipping, brushing, or spraying. Generally used to protect components from environmental and/or handling stresses and applied prior to embedment.

Encapsulating Mold: Four-sided, precision mold is used for the encapsulation of circuit modules. The bottom or fifth side contains the module terminal pins embedded in Silastic. The circuit module is welded to the header pins.

Epoxy: A type of plastic material used to encapsulate or embed component assemblies. May be filled or otherwise modified to vary such characteristics as heat transfer, brittleness, and such. Must be polymerized (cured) to solidify the material.

Etchant: (*1*) A chemical reagent used to reveal structural details of a metal through preferential attack or staining.

(*2*) A chemical reagent used to remove the unwanted portions of a conductive material that is bonded to an insulating substrate.

Exotherm: The characteristic curve of a resin during its cure, which shows the heat of reaction (temperature) versus time. Peak exotherm is the maximum temperature on the curve.

Expulsion: The forcing out of molten material at the interface of two materials being welded, caused by the heat and pressure of the welding cycle.

Fatigue Limit: The maximum stress below which a material can presumably withstand an infinite number of stress cycles.

Feed thru Wire: See **Jumper Wire.**

Filler: A material, usually inert, which is added to plastics to modify physical properties and/or reduce cost.

Film Punch: A precision device for punching holes in matrix and positioning films.

Flagging: Transition connection between outside terminal pins and matrix conductors.

Flash: (*1*) Thin film of molten metal on a weld forced out by the electrode force at the interface of the materials being welded. (See **Expulsion.**)

(*2*) The thin amount of material on a casting which has attempted to enter the mold interface (parting line).

(*3*) An extremely thin amount of plating on a material.

Flexibility or Flexure Capability: The number of repetitive cycles of torsional stressing which a welded joint will withstand before failure of the material or the weld joint. A measure of ductility.

Flexibilizer: A material added to rigid plastics to make them resilient or flexible. Can be either inert or a reactive part of the chemical reaction.

Foams: Cellular materials formed by chemicals which have been added to generate gases upon heating and/or curing or by the introduction of a gas during cure.

Follow-Up: See **Inertia.**

Force Fired: The automatic release of weld energy to the circuit when a preset static electrode force has been reached.

Force Gauge: An instrument for measuring exact pressure applied as head is actuated.

Forge Weld: The result of heating materials to the plastic range below the melting point and applying sufficient force to cause atomic bonding through a rearrangement of the atomic structure along the interface and metal-to-metal contact through broken oxide and/or other films.

Fracture: Irregular surface produced when a metal is ruptured or broken.

Fusion Weld: The definite melting and resolidifying of a weld melt (nugget of a cast structure), surrounded by a heat affected zone (HAZ) of non-melted basis metal whose mechanical properties and microstructure have been altered by the welding heat.

Good Weld: *Metallurgically:* The weld takes place with a minimum change in the basis metal crystallographic structure, is free from cracks or excessive grain segregation, and exhibits a minimum of undesirable intermetallics, with porosity not exceeding that of the basis material.

Mechanically: The weld exhibits breaking strength comparable with the weaker basis metal and possesses suitable fatigue strength for the application.

Electrically: The weld does not affect the circuit as either a thermally sensitive or a resistive junction.

Hardener: A chemical added to a thermosetting resin for the purpose of causing curing or hardening, and which becomes a part of the chemical reaction and chemical composition after curing. (See **Catalyst** and **Accelerator.**)

Head (Welding): That portion of a welding machine which contains the electrodes and at which the weld is actually performed. May be integral with, attached to, or completely separate from (except for electrical connections) the power supply.

Header: A pre-formed part made of an insulating material and containing the input and output leads of a module. May be part of, or attached to, the case by adhesive bond or embedment material. Forms a portion of the outer case of the module.

Heat Affected Zone: That portion of the basis metal which has not been melted, but whose microstructure or properties have been altered by the heat of welding.

Heat Balance: The establishment of a heat gradient curve that focuses maximum heat at the interface of the two materials being welded, and a symmetrical condition about this point.

Heat Distortion: Deformation of a material caused by the application of heat. Heat distortion temperature is the maximum temperature that a material will withstand without deformation.

Heat Sink: A device used to absorb or transfer heat away from heat sensitive parts.

Heat Time: The time of duration of each current impulse in pulsation welding.

Heat Transfer: In embedments or encapsulants, the capability (or lack of it) to distribute the heat generated by components to the outer surfaces of a module.

High Density Packaging: Constructing electronic equipments with a minimum of volume and weight.

Hybrid Circuit: A circuit consisting of any two or more distinct types of circuitry or methods of fabrication (for instance, electron tubes and transistors, thin film, and discreet components).

Impregnation: Application of a resin to tightly built devices (for example, coil windings). The resin penetrates internal voids and a solid assembly results. Impregnation may be used together with embedment or encapsulation.

Inclusions: Non-metallic materials, such as slag and dirt, entrapped during solidification of a molten metal.

Inertia: Tendency to remain in a fixed mode or condition. In welding heads, a lower inertia can permit the electrodes to follow the deformation of the welded materials more closely.

Integrated Circuit: An electronic circuit in which the component parts are produced integrally with, and are inseparable from, the whole (such as by etching, diffusing, or doping).

Interconnection: The physical wiring between components (outside a module), between modules, between units, or between larger portions of a system or systems. Often used synonymously with intraconnection.

Interface: The boundary surface between two different media.

Intraconnection: The physical wiring connections within a module.

Iso-Flex Diagram: A plot of weldment ductility as a function of both electrode force and weld energy. (See also **Weld Profile Chart.**)

Iso-Strength Diagram: A plot of weldment pull strength as a function of both electrode force and weld energy. (See also **Weld Profile Chart.**)

Joint Density: The number of joints or intraconnections per unit or volume.

Jumper Wire: Wire or ribbon used to provide the intraconnections between layers of bus routing.

Laser Welding: A method of welding in which material heating is accomplished by concentration of a beam of coherent light on the area until fusion of the materials takes place.

Log Piled: See **Cordwood.**

Longitudinal: In a plane parallel to the longer axis.

Lot Control: The maintenance of a group of items as a distinct entity according to their physical characteristics, date of manufacture, and/or other criteria.

'L' Test: See ***Torsional Shear.***

Macrostructure: The structure of metals as revealed by examination of a polished specimen at a magnification not exceeding ten diameters.

Master Matrix Film: A master matrix film, as used in circuit and wiring modules, is a piece of photosensitive Mylar or Cronar imprinted with weld point locations, circuit component locations, and other fabrication information.

Matrix: A system of parallel wires on each side of an insulating material, crossing at 90 degrees and forming an intraconnection system for electronic components within the module, or for interconnecting modules within a unit.

Matrix Weld: A weld joining two conductors on opposite sides of the insulating material in a matrix.

Melting Range: The temperature range between solidus and liquidus temperature, the temperature range in which a material melts.

Metallographic: Pertaining to the study of the structure and physical properties of metals and alloys, especially by use of microscope and x-ray.

Micro: Pertaining to metallography, denotes the examination of a material at magnifications greater than ten diameters.

Microcircuit(ry): A generic term used to describe all types of microminiature circuit construction techniques.

Microelectronics: The technique of electronic equipment design and its construction which utilizes microcircuitry.

Micro-Miniaturization: A relative degree of miniaturization resulting from the application of micro systems engineering to obtain a reduction in equipment or assembly volume of at least an order of magnitude over that existing in subminiature equipment.

Microstructure: The structure and internal conditions of metals revealed on a ground, polished, and etched specimen at magnifications greater than ten diameters.

Miniaturization: The process of reducing the volume required by equipment or parts which are presently necessary to perform a given function.

Missed Weld: Complete absence of any indication that an attempt was made to produce a weld joint. A condition occurring when an operator has failed to apply the electrodes to the joint to be welded.

Module (Electronic): A group of electronic parts whose leads are joined by welding, soldering, or other method to form an assembly which is subsequently embedded, encapsulated, and/or placed in a shell, and has fixed external dimensions.

Mold: (*1*) To form a plastic part by compression, transfer, or injection molding, or some other pressure process.

(*2*) Container which determines outside dimensions of an embedded part but which is not a permanent portion of that embedded part.

Mold Release: A material applied to the surfaces of a mold cavity to ease removal of the finished part.

Molten Zone: The area in which the welding cycle heat has completely remelted the material(s) being welded.

Mother Board: A relatively large piece of insulating material on which components, modules, or other electronic subassemblies are mounted and interconnections made by welding, soldering, or other means, using point-to-point or matrix wire, or circuitry fabricated integral with the board.

Nickel: An easily welded material, most commonly used for welded module intraconnects. Also used for component lead material.

No Weld (NW): The lack of a satisfactory bond between the materials being welded, generally occurring when there is insufficient electrode pressure or weld energy, or both.

Nugget: The melted and resolidified metal joining the parts being welded, usually ellipsoidal in cross-section and defined by its cast structure.

Packaging: The process of physically locating, interconnecting, and environmentally protecting electronic devices, components, and assemblies.

Packaging Density: Number of components or component functions per unit volume. May be specified at different levels, namely:

(a) at component level—not including connections

(b) at circuit level—including connections

(c) at equipment level—including components, connections at circuit level and between circuits, cooling arrangements and other mechanical structure, and so on.

The term usually requires clarification in usage concerning its basis; for instance, maximum component size, nominal size, and so on. (See also **Volumetric Efficiency.**)

Parallel Gap Welding: A method of resistance welding in which both electrode tips are in close proximity to each other, being separated by a small gap or insulating material; approach the work from the same direction; and contact only one of the two materials being welded.

Part: Any component piece, electrical or mechanical, used to make up an assembly. One piece, or two or more pieces joined together which are not normally subject to disassembly without destruction of designed use.

Passive Device: A device representing either a resistor, capacitor, or inductor. Does not require any input other than a signal to perform its function.

Pellet Components: Components manufactured in the form of small cylinders without leads. Not used in resistance welded assemblies.

Percussive Welding: A resistance welding process wherein a relatively intense discharge of electrical energy and the application of high pressure (usually a hammer-like blow) occur simultaneously, or with the electrical discharging occurring very slightly before the application of the pressure or hammer blow.

Photomicrograph: Photo taken of the surface of a specimen, usually etched, at magnifications greater than ten diameters.

Pin Outs: The external wires or pins on a module (generally having a circuit function).

Planar: Existing essentially in a single plane. A packaging method in which the basic assembly is only one component thick (see **Card**). More than one basic assembly may be assembled together within a module.

Plastic Deformation: Deformation that will remain permanent after removal of the load which caused it.

Plating: Formation of an adherent layer of metal upon an object.

Point-to-Point Wiring: A method of forming circuit paths by connecting the various devices, components, modules, and such, with individual pieces of wire or ribbon. May be soldered, welded, or attached by other means.

Polymer: See **Resin.**

Polyurethane: A type of plastic material used to encapsulate or embed component assemblies. Often used in the foamed condition for lighter weight or thermal insulation.

Positioning Film: These are polyester film sheets indicating full size, the arrangement of components, the location of the components via designations (for instance R11), polarity, and appropriate locations of component lead holes to be punched.

Postheating: Application of heat to a weld zone immediately after welding for tempering purposes. Provides a controlled rate of cooling to avoid a hard or brittle structure.

Pot: To embed a component or assembly in a liquid resin using a case, shell, or other container which remains as an integral part of the product after the resin is cured. (See also **Embed and Cast.**)

Power Density: The average amount of power dissipated per unit volume, usually specified in watts per cubic inch.

Power Supply: That portion of a welding machine which converts the AC input power into the type of energy necessary to perform the welding cycle and controls it accordingly. (See also **Head.**)

Pressure Weld: That joint obtained between two pieces of material by applying heat, pressure, or both to produce a localized union by interatomic attraction of the two materials at their interface.

Printed Circuit: A pattern comprising component parts, wiring, or a combination thereof, all formed in a predetermined design on a common insulating base. Usually the pattern is formed by etching away unwanted material or by depositing the conducting material.

Printed Wiring: A pattern of conductors only formed on a common insulating base. (See also **Printed Circuit.**)

Project Welding: A resistance welding process wherein localization of heat between two or more surfaces or between the end of one member and surface of another is affected by projections.

Pull Strength: The amount of force (in pounds) necessary to break a piece of material or a weld joint when loaded or pulled in a straight line at a constant rate. Rate of pull is in inches per minute.

Pull Test: The subjecting of a specimen of wire or a weld to 180 degrees loading to determine its breaking strength.

Pulse Arc Welding: A type of welding in which the material to be welded is positioned together, forming one electrode. The other electrode is positioned to form a gap with one of the work pieces. An arc is struck and the current heats the work pieces to the melting point at their interface. (See also **Arc Percussive Welding.**)

Pulse Length or Width: The time during which weld energy is being delivered through the electrodes. Usually specified as average time in milliseconds taken at some percentage of pulse height.

Pulse Shape: The energy versus time curve of the welding cycle taken at the electrodes.

Range: A measure of variability. Difference between highest and lowest value. In welding, the area contained between the highest and lowest settings of weld energy and electrode force which will produce acceptable welds. In weld testing, the maximum minus minimum pull strength value of a group of specimens.

$\bar{R}$ ('R' Bar): The arithmetical average of a group of range values.

Residual Stress: Stress present in a body that is free from external forces or thermal gradients.

Resin: High molecular weight organic material with no sharp melting point. For most purposes, the terms resin, polymer, and plastic can be used interchangeably.

Resistance Weld: The junction produced by heat obtained from resistance of the work to the flow of electric current in a circuit of which the work is a part and by the application of pressure before and during the flow of current. The term includes all type bonds produced by the process which may or may not be classified metallurgically as welds.

Ribbon: A common intraconnecting material, usually nickel, of rectangular cross section, which is used to connect the electronic parts or modules together in the form of a functioning circuit.

RTV: Room Temperature Vulcanizing. Refers to a type of silicone compound which vulcanizes at room temperature. Used as an encapsulant, embedment, or molding form.

Sampling Rate: In relation to time or to number of welds, the rate at which samples of the same materials are made and (pull) tested.

Series Welding: A resistance welding process wherein two or more welds are made simultaneously by a single welding transformer with the total current passing through every weld.

Set Down: Total thickness of materials to be welded measured before welding minus the thickness after welding. Usually measured in percent of original thickness.

Sheath: See **Clad.**

Shell: See **Case.**

Shrinkage: *(1) Contractions of an embedment material which occur during cure cycle.*

(2) Contractions of the melted zone of a weld upon cooling and solidification.

Shrinkage Cracks: Cracks which develop in a cast material because of thermal contraction during solidification. Cracks may not appear until some time after solidification.

Spitting: A condition occurring during the weld cycle in which small amounts of material are rather violently expelled from the weld area. Usually caused by improper energy and/or force being applied, or to lack of cleanliness in the materials or electrode tips.

Splashed Weld: General term for a weld in which there has been an excessive expulsion of material.

Spot Welding: A resistance welding process wherein the fusion is confined to a relatively small portion of the area of the lapped parts to be joined by the shape or contour of one or both welding electrodes.

Standard Deviation: The square root of the average of the squared deviations from the arithmetic mean.

Stored Energy Welder: See **DC Welder.**

Temper: The hardness and strength produced by mechanical or thermal treatment or both, and characterized by a certain structure, mechanical properties, or reduction in area during cold working. A measurement of the degree of hardness or lack of ductility in a metal.

Tensile Strength: Value obtained by dividing maximum load observed during tensile straining by specimen cross-sectional area before straining. Sometimes used incorrectly but synonomously, for the term **Pull Strength.**

Tensile Test: Subjecting a specimen to uniaxial tensile stresses resulting from loads applied to opposite ends of a specimen. Term is sometimes used erroneously to describe **Pull Test.**

Thermal Conductivity: A measure of the ability of a material to conduct heat.

Thermal Expansion: Increase in size of a material caused by the application of heat.

Thermal Shock: The sudden application of a hot or cold environment. Usually used to induce stresses within an embedded nodule to determine if failure will occur.

Thermocompression Bonding: The joining together of two materials without an intermediate material by the application of pressure and heat in the absence of electrical current through the materials.

Thermoplastic: Capable of returning to a plastic or liquid state by the application of heat.

Thermosetting: After initial heating to a plastic or liquid state, will solidify and cannot be returned to a plastic or liquid state by the re-application of heat without destruction.

Thin Film: A thin layer deposited onto a thicker substrate of different chemical composition.

Throat Depth: The distance from the center line of the electrodes to the first obstruction limiting the insertion of the work. Usually measured in a horizontal plane.

Throat Opening: The variable dimension between the inner surfaces of current-carrying members (arms, knees, or platens, and such) taken at right angle to the measurement of throat depth.

Tip Pickup: Contamination of the electrode tips caused by affinity to the materials being welded.

Torsion: Strain created in a material by a twisting action. Correspondingly, the stress within the material resisting the twisting.

Torsional Shear: A method of weld joint testing in which an 'L' shaped specimen is clamped at the ends of the 'L' and pull tested, subjecting the weld joint to a combination torsional and shear loading.

'T' Test: A method of weld joint testing in which a 'T' shaped specimen is clamped on both sides of the cross and at the lower extremity of the 'T' and pull tested, subjecting the weld joint to a shear loading only.

Transverse: In a plane perpendicular to the longer axis.

Type 'D' Wire: A standardized material (MIL–STD–1276) for weldable component leads consisting of a gold plated, copper clad, nickel-iron core alloy.

Type 'K' Wire: A standardized material (MIL–STD–1276) for weldable component leads consisting of a gold plated iron-nickel-cobalt alloy.

Type 'N–1' and 'N–2' Wire or Ribbon: A standardized material consisting of high purity nickel. Type 'N–1' is unplated and type 'N–2' is gold plated (MIL–STD–1276).

Ultrasonic Welding: A method of welding in which electrical energy is transformed into high frequency (ultrasonic) vibrational energy and supplied, with pressure, to the materials to be joined, creating a mechanical bond.

Vacuum Casting: (*1*) *Complete:* A method of embedding modules in which the resin is de-aired by placing in a chamber, drawing a vacuum, and pouring into the module without removing the resin from the vacuum.

(*2*) *Partial:* The module is de-aired under vacuum after pouring. The resin may or may not be de-aired before pouring.

Variance: The square of the standard deviation.

Viscosity: A measure of the resistance to flowing of, a liquid or plastic state material.

Volcanic Effect: A type of molten material expulsion from a weld, characterized by a visual similarity to lava flowed from a volcano.

Volumetric Efficiency: Ratio of parts volume to total equipment volume expressed in percent. Sometimes called packing factor. In modules, usually taken as volume of component bodies only (not including leads, other interconnecting media, insulators, heatsinks, and so on) and based on nominal sizes of components and nominal outside module dimensions.

Wafer Board: An insulating board used in positioning the components in a module. Does not contain integral circuitry. Similar to film except thicker.

Watt Second: A measurement of welding heat or weld energy equal to 0.24 calories. One of the two parameters (the other: electrode force) commonly referred to on weld schedules. Note: Watt-second meters are generally voltmeters with converted scales.

Weld: A localized coalescence of metal by heating to suitable temperatures and applying pressure. In this method of resistance welding, there is no use of a filler material.

Weldability: The capacity of a metal to be welded.

Weld Head: See **Head.**

Welding: Joining two or more pieces of material by applying heat, pressure, or both, with or without filler material, to produce a localized union through fusion or recrystallization across the interface. The term may also be extended to include brazing, in which an intermediate material (usually the plating or cladding on the materials on electronic component leads) melts below the temperature of the basis materials and creates the joint.

Welding Pressure: External force applied in the pressure welding processes to control the current density throughout the weld, or heat effects, or both.

Welding Stress: The stress resulting from localized heating and cooling of a metal during welding.

Weld Joint: A union of two or more metals produced by application of the welding process.

Weld period: The time required for one complete cycle of a welding operation.

Weld Polarity: Certain material combinations have a different resistance to weld current, depending on the direction of current flow. In DC welding, a suitable weld may be possible in only one direction of current flow. A weld schedule must define the proper polarity for such cases.

Weld Profile Chart: A plot of weldment pull strength (or flexure cycles) as a function of weld energy, holding electrode force constant. Also called **Constant Force Chart.**

Weld Schedule: A document listing the force and energy parameters along with other pertinent data required for the welding of two materials using a specified type of equipment.

Weld-thru Hole: A hole located at a crossover point in a matrix film. See **Matrix Weld** and **Jumper Wire.**

Weld Time: The interval during which current is allowed to flow through the work during the performance of one weld. In pulsation welding, the weld period includes the "cool" time intervals.

Wiping: The movement of the electrodes in the horizontal plane as force is applied.

Wire Wrap: An electrical connection made between a wire and a terminal which has sharp corners by wrapping several turns of closely spaced solid wire under tension around the terminal. The connection is held together thereafter by residual stresses in the parts.

Wiring Matrix: A wiring matrix is a master matrix film with wire or ribbon on both sides, duplicaiting the circuit paths indicated on the master film. Where weld points are indicated, holes are punched in the master film. Wire or ribbon is then loaded into the film, and a weld made through the punched hole connecting a conductor on the bottom of the film. The film otherwise shields the two layers of wiring.

Work Hardness: An increase in the hardness of a metal caused by the plastic deformation at temperatures below the recrystallization range. The hardness developed in a metal as a result of cold working.

X ('X Bar'): A symbol representing the arithmetical mean of a group of data. In the resistance welding process, it is generally used to depict the average pull strength values of weld test specimens.

APPENDIX A

MSFC–SPEC–270
MAY 20, 1964

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
SPECIFICATION

COMPONENT LEAD AND INTERCONNECTION MATERIALS, FOR WELDED ELCTRONIC MODULES

1. SCOPE

1.1 This specification establishes the requirements for resistance spot welding materials for use in interconnecting electronic components.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise specified, the issue in effect on the date of invitation for bids shall apply.

SPECIFICATIONS

Federal

Federal Test Method Standard Number 151____ Metals; Test Methods.

Military

MIL–G–45204__ Gold Plating (Electrodeposited).

STANDARDS

George C. Marshall Space Flight Center

MSFC–STD–271__ Fabrication of Welded Electronic Modules, Standard for.

PUBLICATIONS

National Aeronautics and Space Administration

NPC 200-2---- Quality Program Provisions for Space System Contractors.

NPC 200-3---- Inspection System Provisions for Suppliers of Space Materials, Parts, Components, and Services.

APPENDIX B

Assembler/Operator Course

Orientation
- Why Weld
- Basic Theory
- Quality Standards
- Operator/Inspector Responsibilities

Equipment Familiarization
- Safety Precautions
  - Power Supply
    - Function
    - Operation
  - Weld Head
    - Function
    - Operation
  - Electrodes
    - Function
    - Types and Factors in Selection
  - Materials
    - Nickel
    - Kovar
    - Dumet
  - Weld Technique
    - Electrode Inspection and Maintenance
    - Material Placement
    - Head Actuation
  - Weld Inspection
    - General
      - Difficulty of Inspection
      - Role of Pull Tests and Metallurgical Examination

Visual Inspection
- Weld Defects and Causes
- Use on Microscope

Remedial Action Requirement

Equipment Familiarization and Weld Practice
- Power Supply
  - Energy Control(s) and Meter

Equipment Familiarization and Weld Practice—Continued
- Head Actuation
  - Proper Technique
  - Use of Force Gauge
- Welding
  - Precut Lengths of Materials

Packaging Methods
- Point-to-Point
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- Header
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- Interpreting Film Symbols
- Punching
- Selection and Inspection of Dies
- Defects
- Loading of Matrix Film

Holding Fixtures
- Purpose
- Proper Use of Film Placement

Film Loading
- Techniques
- Observation of Component Polarity
- Film Punching
- Fixture Use
- Film Loading

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- Discussion of Basic Electronic Components
- Common Lead Materials

Component Inspection
- Bent Leads
- Cracked Glass Seals
- Plating Defects
- Nicked Leads

Component Identification
- Color Coding
- Polarity

- Documentation
  - Drawing System and Interpretation
  - Process Documentation
  - Weld Sequence List
  - Other Documentation
- Workmanship and Quality Standards
  - Hand Tools
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    - Inspection
  - Handling of Modules and Components
  - Applicable Specifications and Standards
- Module Assembly and Welding
  - Matrix Assembly
    - Film Punching
    - Matrix Film Loading
    - Matrix Welding
    - Matrix Clipping
    - Inspection
- Fixture Use and Loading of Positioning Films
- Component Loading
- Welding of Matrix to Module
- Component Lead Clipping

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